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ANALYSIS OF A METHOD FOR OPTIMUM DESIGN OF WATERJET PROPULSION SYSTEMS.

Dennis Keith Kruse

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ANALYSIS OF A METHOD FOR OPTIMUM DESIGN OF WATERJET PROPULSION SYSTEMS

by

Dennis Keith Kruse

B.S., U. S. Naval Academy

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ANALYSIS OF A METHOD FOR OPTIMUM DESIGN OF WATERJET PROPULSION SYSTEMS

by

Dennis Keith Kruse

Submitted to the Department of Ocean Engineering on May 11, 1973, in partial fulfillment of the requirements for degrees of Ocean Engineer and Master of Science in Mechanical Engineering.

ABSTRACT

An existing computerized method for optimum design of waterjet propulsion systems for sub-cavitating hydrofoil craft is analyzed for sensitivity to variations in normally fixed parameters and for sensitivity to variations in the starting points for the search used in the optimization procedure. A compatible method for off design evaluation of waterjet propulsion systems is developed and incorporated into the optimization program in a manner which permits off design evaluation to be performed separately or in conjunction with design. The evaluation routine requires that system geometry, craft characteristics and pump characteristics be specified. System drag and losses are calculated to determine required flow rate and pump head and the corresponding pump speed, efficiency and required power are determined. Results of design optimization for a series of similar craft are presented and show a strong sensitivity to the input estimate of the take-off drag. Sensitivity to starting values of the independent variables was noted in some cases and appears to be due to the fact that jet velocity ratio dominates the other independent variables as an influence on total system weight. A FORTRAN computer listing and sample inputs and outputs for both design and evaluation routines are included.

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SYMBOLS USED IN TEXT

Symbol	Definition
A	area
A_s	nacelle surface area
C	nacelle diffuser expansion loss factor
C_d	nacelle drag coefficient
C_{ds}	strut drag coefficient
C_{dsp}	spray drag coefficient
C_f	Schoenherr friction coefficient
C_s	Factor for strut diffuser expansion loss
c	strut chord
D	diameter
d_m	mean diameter
f	Moody pipe friction factor
g	acceleration of gravity
h	head loss
H_a	atmospheric head
H_{sv}	net positive suction head
K_e	strut diffuser expansion loss coefficient
K_j	junction mixing loss coefficient
K_t	form loss coefficient
L	nacelle forebody length
L_d	nacelle diffuser length
N	pump RPM
P	total pressure
p	static pressure

Symbol	Definition
pv	vapor pressure
Q	volume flow rate
q	dynamic pressure
RPR	ram pressure recovery factor
R	bend radius of elbow centerline
RO	elbow internal duct radius
S	suction specific speed
T	thrust
t	strut thickness
V	velocity
α	angle of attack
β	nozzle depression angle
θ	diffuser half angle
λ	divergence loss factor
ρ	density of salt water
σ	cavitation number
ϕ	junction angle

Subscript	Definition
aux	auxiliary inlet
c	combined main and auxiliary flow
i	main inlet
j	jet
n	nacelle
t	nozzle throat
o	free stream condition

Subscript	Description
1	nacelle inlet
2	nacelle diffuser exit
6	pump inlet

1. INTRODUCTION

Waterjet propulsion has attracted growing interest in recent years due, in part, to the trend toward the development of faster and more non-conventional vehicle types such as hydrofoils and surface-effect ships. These vehicles have made the potential advantages of waterjet propulsion systems more attractive, while at the same time lessening some of its disadvantages. Among the possible advantages are:

a. Reduced vibrations and avoidance of propeller cavitation noise

b. Fewer system components

c. Elimination of underwater appendages

d. Simpler transmission machinery

e. Capable of use in shallow water operations

f. Steering control directly from the propulsor

Additionally, the low overall system efficiency which causes waterjet propulsion to compare unfavorably with conventional propulsion systems at lower speeds is less of a penalty at higher speeds.

In light of the increasing interest waterjet propulsion, a number of studies have been made reviewing the important parameters involved in the selection of system components; as well as considerations for overall system design. This led naturally to efforts to computerize the design process and the most recent, and most comprehensive, of these efforts is the computerized method for design optimization of waterjet propul-

sion systems for hydrofoils developed by R.P. Gill, B.T. Conner, and R.C. Percival(references 1, 2 and 3).

It is desirable to have a compatible method of evaluating existing or proposed systems which can be used in conjunction with such a design method. This will enable existing systems, as well as alternative design proposals, to be evaluated on a common basis with the computer produced optimum design. It would also permit the performance of the computer produced design, or any other design, to be predicted at speeds other than the design speeds.

This report presents a revision of the computerized design method developed by Gill, Conner and Percival which permits it to be used for system evaluation as well as for its original purpose of design. The inclusion of the evaluation program within the design program permits common portions of the program to be used for both evaluation and design and also permits the off-design performance to be predicted in conjunction with the design computations. Additionally, it will permit the accuracy of the program to be analyzed since it can be used to predict the performance of existing systems and the predicted performance can then be compared with measured performance. This could lead ultimately to refinements and improvements in both the design and evaluation portions of the program.

This report describes the methodology used in the program, presents an analysis of results obtained by using the program, and provides a users' manual as an aid in utilizing the program

and interpreting the output obtained from the program. The methodology used for evaluation is presented in detail, and the design routine is summarized briefly. The design routine has been analyzed for sensitivity of a basic design to variations in normally fixed parameters and to variations in intial values of the independent variables. The evaluation routine has been tested by evaluating the performance of a system designed by the program at design and off-design conditions. The users' manual, contained in appendices to this report, describes the use of the program for design as well as for evaluation; and it contains listings of required and optional inputs, sample controlling programs, and sample outputs.

2. METHODOLOGY USED FOR EVALUATION

2.1 ASSUMED GENERAL SYSTEM CONFIGURATION

The general configuration of the waterjet propulsion system used for the evaluation routine is the same as that which is used in the design routine, and is depicted in Figure 1. The components of the system, in order from inlet to output, are:

1. The nacelle or ram inlet, which includes the auxiliary inlet, if any, and which is assumed to be of a subcavitating type for the calculations.
2. The strut elbow which derects flow from the nacelle into the strut and which generally contains either splitter vanes or turning vanes to reduce internal losses.
3. The strut which supports the foils and carries the water into the hull, and which is generally used as a diffuser in order to avoid cavitation in the pump inlet piping.
4. The hull elbow which directs the flow from the strut to the pump inlet piping.
5. The pump inlet piping which consists of one or two elbows and either a junction, divergence or straight pipe depending upon the total number of pumps used.
6. The pump which is driven by a gas turbine engine through a reduction gear.
7. The nozzle or jet which discharges the water through

either the transom or the bottom of the hydrofoil at a high speed thereby producing the required thrust.

The program assumes that the usual two strut configuration is utilized.

2.2 GENERAL PROCEDURE FOR EVALUATION

The evaluation procedure assumes that the geometry of the system is defined in its entirety and that a reliable estimate of ship drag, ie. that portion of total drag not directly attributable to propulsion system components, is available for the speeds at which the system will be evaluated. Estimated values of those components of drag due to the propulsion system; ie. nacelle drag, strut drag and spray drag, are added to the ship drag to obtain the estimated total drag and, therefore, the estimated required thrust. The required flow rate and jet velocity are related to the required thrust by the equation,

$$T = \rho Q(V_j \cos(\beta) - V_o) \qquad (1)$$

The required flow rate and required jet velocity, as well as the required nacelle inlet velocity, can thus be determined by using equation (1) together with the one-dimensional continuity equation for an incompressible fluid,

$$A_i V_i = A_j V_j = Q \qquad (2)$$

The flow rate and inlet and jet velocities, together with the system geometry, are sufficient to permit calculation of all of the head losses in the system ducting. The total system head loss and the flow rate can then be used to calculate the required pump speed and shaft horsepower.

The required flow rate and inlet velocity, together with ship speed and system geometry, are also used to calculate revised estimates of nacelle drag, strut drag and spray drag. These values are added to ship drag to obtain a new estimate of total drag. If the revised total drag differs by more than one per-cent from the previous estimate of the total drag, the new estimate is used to calculate a new flow rate and new inlet and jet velocities. The procedure is then repeated until a total drag estimate is obtained which differs by less than one-percent from the previous estimate. The calculated system performance is then output by the program.

The evaluation routine also calculates the structural weight of the system components and the weight of water entrained in the system using the same methods as those used in the design routine. This provides an additional check to ensure that the evaluated system is the same as the designed system. Additionally, when an existing system is evaluated, the calculated weights may be compared with actual weights in order to provide a check of the weight prediction methods used in the program. This could eventually result in improvements in the weight estimation models used.

2.3 SPECIFIC EVALUATION METHODOLOGY

The evaluation routine is begun by inputting the required parameters to the program and calculating the required flow rate and jet and inlet velocities in the manner described in the previous section. The parameters which must be input to the

program are:

a. Displacement

b. Prime mover

c. Cross sectional areas and shapes of all system components

d. Lengths of all system components

e. Bend angles of all elbows in the system

f. Nozzle depression angle

g. Pump type and number of stages

h. Pump blade tip diameter

i. Pump characteristics at design specific speed

j. Depth of submergence of nacelle

k. Height of pump centerline above waterline

l. Craft speeds for which system is to be evaluated

m. Craft drag at evaluation speeds

A more detailed list of both required and optional inputs, including the required dimensions and the variable names used in the program, is contained in Appendix C.

Since it is assumed that the system is of a subcavitating design, an important consideration in the evaluation of system performance is a check to determine whether cavitation is occurring within the system at the evaluation speed. Checks for cavitation are made for those points in the system where it is deemed most likely to occur. Within the program, cavitation calculations are performed concurrently with other calculations; but, for the sake of clarity and continuity in this report, they will be described separately in section 2.4.

Head loss, drag and estimated weight calculations are performed for each component consecutively in the order in which the flow passes through them, thus the first component to be evaluated is the nacelle. Losses in the nacelle are calculated as three separate components; lip losses, pipe losses and diffuser losses.

When the nacelle subroutine is entered during evaluation, the first operations performed are the calculation of inlet velocity ratio, V_i/V_o from the input values of V_i and V_o; and calculation of free stream static pressure, free stream dynamic pressure, incipient cavitation number, and total pressure for the evaluation speeds.

$$q_o = \tfrac{1}{2}\rho V_o^2$$

$$\sigma_{oi} = (p_o - p_v)/q_o$$

$$P_o = p_o + q_o$$

After checking for external cavitation and for cavitation on the inlet lip, as described in section 2.4, the subroutine proceeds with the calculation of lip losses. Lip losses are calculated differently depending on whether or not a positive indication of inlet lip cavitation was obtained. If cavitation was indicated, the auxiliary inlet area which must be used to avoid cavitation is calculated. To accomplish this, the first step is determining the maximum permissible inlet velocity ratio by interpolating in the data tables.[1]

---

[1] The data tables referred to in discussion of the nacelle eval-

uation are the same as those used in the design routine and are tabulations of the information contained in Tables 1 through 12 and Figures 4 through 20 of reference 2.

$$(V_i/V_o)_{max} = f(L/D_m, \sigma_{oi}, \alpha)$$

The required auxiliary flow rate is then calculated.

$$Q_{aux} = Q_c - Q_i$$

Where

$$Q_i = A_i \, (V_i/V_o)_{max} \, V_o$$

and Q_c is the required total flow per nacelle.

The ram pressure recovery of the lip is a tabulated function of the inlet velocity ratio, now limited to (V_i/V_o)max. The total pressure inside the lip is thus

$$P_i = RPR_{lip} q_o + p_o$$

and the static pressure inside the lip is

$$P_i = P_i - \tfrac{1}{2}\rho V_i^2.$$

Pressure recovery of the auxiliary inlet was assumed to be 0.8. The total pressure inside the auxiliary is then given by

$$P_{aux} = RPR_{aux} q_o + p_o$$

The static pressure inside the auxiliary inlet must be the same as that previously calculated for inside the main inlet lip. Therefore, the velocity through the auxiliary inlet can be determined by

$$V_{aux} = \left[2(P_{aux} - P_i)/\rho\right]^{\frac{1}{2}}.$$

The auxiliary inlet area required is then

$$A_{aux} = Q_{aux}/V_{aux}.$$

If this area is less than the total available auxiliary

inlet area, the total pressure of the combined flow is calculated as the mass weighted average of the combining flows.

$$P_c = (Q_{aux}P_{aux} + Q_iP_i)/Q_c$$

The average velocity of the combined flow is calculated from the dynamic pressure

$$V_i = [2(P_c - p_i)/\rho]^{\frac{1}{2}}$$

and the losses are then obtained directly from the pressure recovery coefficient to this point, which is

$$RPR_c = (P_c - p_o)/q_o.$$

If lip cavitation was not indicated initially, then no auxiliary inlet area is required to be used, and the ram pressure recovery coefficient of the lip is determined directly as a tabulated function of V_i/V_o.

$$\Delta P_d = CK_tq_i$$

where C is the diffuser expansion loss factor and K_t is the form loss coefficient.

$$C = 3.19\text{x}10^{-3}\theta^2 + 8.452\text{x}10^{-4}\theta$$

$$K_t = (1 - A_1/A_2)^2$$

θ is the diffuser half angle.

$$\theta = \tan^{-1}[(D_2 - D_1)/2L_d]$$

Pipe loss in the diffuser is

$$\Delta P = f(L_d/d_m)q_i$$

where f is the Moody pipe friction factor which is calculated within the routine as a function of Reynold's number.

Total internal losses in the nacelle are then

$$\Delta P_n = (1-P_c)(\tfrac{1}{2}\rho V_o^2) + [CK_t + f(L_d/d_m) + fL_{aux}]\tfrac{1}{2}\rho V_i^2.$$

The nacelle drag coefficient is given by

$$C_D = C_f \; 1 + 1.5(D_m/L_N)^{3/2} + 7(D_m/L_N)^3$$

where C_f is the Schoenherr friction coefficient which is calculated as a function of Reynold's number in a seperate subroutine.

The total external drag is then

$$D = C_D \tfrac{1}{2} \rho V_o^2 A$$

where A is the external surface area of the nacelle, calculated in the same way as in the design routine, reference 2.

Calculations for the strut elbow are performed by the same subroutine that handles all of the elbows in the system and calculations for all of the elbows are performed in the same manner as in the design. For purpose of the calculations an elbow is fully defined by specifying the following parameters: width, depth, cross sectional area, bend angle, and radius ratio. The radius ratio, R/RO, is the ratio of the radius of the centerline of the bend to the internal radius of the duct. The inlet and outlet cross sectional areas are assumed to be equal.

In order to maintain compatibility with the design routine, the shapes of the elbows are assumed to be the same as the shapes which are assumed in the design routine. Specifically, the strut elbow is assumed to be rectangular with the depth equal to twice the width, the hull elbow is assumed to be rectangular with the depth equal to one half the width, and the pump elbow is assumed to be circular in shape. The radius ratios and bend angles may be specified in the calling program; but,

if they are not, they will be assigned the same values as in the design program. The cross sectional areas must be specified.

The strut subroutine requires that the thickness to chord ratio, the thickness and chord at the root, the thickness and chord at the tip, and the inlet and outlet areas be specified. The shape of the strut internal ducting is assumed to be the same as that of the strut elbow. The strut length and the diffuser equivalent angle, 2θ, need not be specified as they are calculated within the subroutine from other specified parameters.

The head losses within the strut diffuser are a combination of friction losses and expansion losses. The friction loss coefficient is the Moody friction factor, calculated in the same manner as in the nacelle subroutine. The expansion loss coefficient is given by

$$K_e = C_s(1-A_i/A_o)^2$$

where C_s is dependent upon the diffuser equivalent angle, 2θ, and is determined by interpolation in data tables contained in the subroutine.

Two external drag components, strut drag and spray drag, are attributable to the strut and are calculated in the strut subroutine. The drag coefficients for both components are calculated as functions of the thickness to chord ratio. The strut drag coefficient is given by

$$C_{ds} = 2C_{fs}[1 + 2(t/c) + 60(t/c)^4]$$

and the spray drag coefficient is

$$C_{dsp} = 0.03(t/c).$$

The hull elbow losses are determined in the same manner as previously described for the strut elbow. It may be noted, however, that the assumed shape for the hull elbow gives it a more favorable aspect ratio than that of the strut elbow. This, together with the lower inflow velocity due to diffusion in the strut, will result in lower losses in the hull elbow than in the strut elbow.

The pump inlet piping is that portion of the ducting which connects the hull elbow to the pump inlet. It consists of a straight pipe, the pump elbow, and a transition piece which is either a junction, divergence, or another straight pipe depending on whether there are one, four, or two pumps respectively.

The geometry of the pump inlet piping is basically determined by previous assumptions and previously required inputs with the only remaining variables being cross sectional area of the piping and the junction angle, ϕ. The assumption is made that the mean velocity is constant throughout the pump inlet piping, thus the areas of the ducting are fixed by specifying the area of the hull elbow. The junction angle is assumed to be zero unless otherwise specified. The divergence angle need not be specified since it is calculated within the routine as a function of the distance between the specified pump location and the specified strut location.

The athwartships pipe makes a transition from a rectangular shape to a circular shape, but losses due to change of

shape are neglected in the calculations. Losses in all straight pipe sections are calculated using the Moody friction factor in the manner previously described. Losses for the pump elbow are calculated in the same manner as for the other elbows in the system.

The mixing loss coefficient is dependent on the junction angle, 0, and the divergence loss factor, λ, and is determined by

$$K_j = 1 + \lambda - 2\cos(f(\phi))$$

where

$$f(\phi) = 1.4\phi - 0.00583\phi^2.$$

The divergence loss factor is computed by interpolation in a data table which is taken from Figure 15 of reference 1. When a divergence is used, another elbow is required at the pump entrance. This elbow is treated in the same manner as the other elbows except that the angle of the bend is equal to the divergence angle.

The input parameters required for the nozzle calculations are throat area, jet area, and nozzle depression angle. Nozzle length is calculated from the pump exit position and the nozzle depression angle. Nozzle head loss is calculated in the same manner as in the design routine, where head loss is given by

$$h_n = [f(L_j/2)/(D_t - D_j) \quad 1 - 16/(1 + D_t)^4]V_j^2/D_j 2g$$

when D_j is greater than 1. For D_j less than 1, head loss is assumed to be 1.5% of dynamic head.

With all head losses in the system having thus been deter-

mined; they are then summed, the required pump head is calculated and the pump subroutine is entered for calculation of pump performance. The required pump head is given by

$$H_p = (V_j^2 - V_o^2)/2g + h_{elev} + \Delta h_{total}.$$

The calculations of pump performance are performed in essentially the same manner as that used by the design routine for calculating performance at cruise speed. These methods are described in detail in reference 3 and will only be summarized here, with emphasis placed on the points where the evaluation routine differs.

The input parameters to the pump subroutines for evaluation are pump length, pump type, number of impellers, impeller tip diameter, and a set of performance characteristics which are representative of the design condition; ie. a pump speed, pump head and flow rate which are representative of the design specific speed of the pump. Additionally, the subroutine utilizes the required flow rate, required pump head, and various craft characteristics which are either input or calculated elsewhere in the evaluation routine.

As in the design routine, the pump characteristic head and efficiency curves are assumed to be parabolic and off-design pump speed and efficiency are calculated on that basis. The off-design pump speed is obtained from the equation

$$H/H_D = A(Q/Q_D)^2 + B(Q/Q_D)(N/N_D) + C(N/N_D)^2$$

where subscript D indicates the design condition. The equation is solved for N, which is the off-design pump speed. The coef-

ficients, A, B and C, are determined for the particular pump type in the same manner as in the design routine. The off-design efficiency is calculated in an identical manner after the design point efficiency has first been determined as a function of impeller tip diameter in the same way as in the design routine.

In the design routine, the flow coefficient, head coefficient and suction specific speed are determined and output for the design condition only. In the evaluation routine these parameters are determined and output for the evaluated conditions in order to more fully describe the pump performance at these conditions.

During design, the pump subroutine calls the gear and fuel subroutines which are used to calculate reduction gear weight and weight of fuel required for specified endurance at cruise speed. These subroutines are also called during evaluation, but their use is somewhat different than in design. For evaluation the gear ratio must be specified whereas in design it is calculated as the ratio of prime mover design speed to pump design speed. The type of reduction gear may be either specified, or selected on the basis of gear ratio and number of inputs and outputs in both design and evaluation routines. The fuel subroutine does not calculate a fuel weight during evaluation, but instead, it calculates the fuel consumption rate at the evaluated speed, assuming the craft is at specified displacement. If the fuel weight is desired to be included in the

total system weight output at the end of evaluation, it must be specified in the inputs.

2.4 CAVITATION CONSIDERATIONS

There are six points, two external and four internal, where cavitation is most likely to occur, and an important part of the evaluation of a system is a determination of whether cavitation is expected to occur at any of these points at the evaluated speeds. The six points which must be checked for cavitation are:

1. The exterior surface of the nacelle.
2. The exterior surface of the strut.
3. Inside the nacelle inlet lip.
4. Inside the strut elbow.
5. At the pump inlet.
6. On the pump impeller.

The check for cavitation on the exterior of the nacelle is accomplished by interpolating in a data table to obtain the forebody length to maximum diameter ratio, L/D_m, for a nacelle having an external pressure coefficient equal to the negative of the free stream incipient cavitation number. The inlet to maximum diameter ratio, D_i/D_m, corresponding to this L/D_m is determined by interpolating in another data table. This value is compared with the actual D_i/D_m and if the actual value is greater cavitation can be expected to occur and an indication to that effect is printed in the output data.

The cavitation number for flow around a strut can be approximated by

$$\sigma = [1.15(t/c) + 1]^2 - 1.$$

The incipient cavitation number for flow around the strut is

$$\sigma_i = (H_a - p_v)g/\tfrac{1}{2}(1.137V_o)^2.$$

If $\sigma_i < \sigma$ at the evaluated speed, then cavitation is likely and is so indicated in the output data.

The check for cavitation on the inside of the nacelle inlet lip is accomplished by interpolating in a data table to determine the limiting inlet velocity ratio beyond which cavitation will occur inside the lip.

$$(V_i/V_o)_{max} = f(L/D_m, \sigma_{oi}, \alpha)$$

If V_i/V_o at the evaluated condition is greater than $(V_i/V_o)_{max}$ cavitation will occur unless sufficient auxiliary flow is provided to reduce the effective inlet velocity to that corresponding to $(V_i/V_o)_{max}$.

The auxiliary inlet area required to provide sufficient auxiliary flow to avoid cavitation is calculated in the manner described in Section 2.3. If the required auxiliary inlet area is greater than the available auxiliary inlet area, then cavitation can not be avoided and the output of the program will indicate that inlet lip cavitation will occur at the evaluated speed. If cavitation can be avoided only by using some portion of the auxiliary inlet area, then the output will indicate the auxiliary inlet area which is required.

The incipient cavitation number on the turning vanes in the strut elbow is given by

$$\sigma_{tvi} = (p_2 - p_v)/(\tfrac{1}{2}\rho V_2^2)$$

where subscript 2 indicates conditions at the exit of the nacelle

diffuser. The incipient cavitation number, σ_{tvi}, is a characteristic number which has been determined experimentally, thus the critical velocity at the diffuser exit can be determined.

$$V_{crit} = [\sigma_{oi} + 1 - P_{loss}/(\tfrac{1}{2}\rho V_o^2)]^{\frac{1}{2}} [V_o/(1 + \sigma_{tvi})^{\frac{1}{2}}].$$

These two values are compared. If V_2 max is greater than V_{crit} cavitation is likely to occur and will be indicated in the program output.

Cavitation is assumed to occur in the pump inlet if the local static pressure, p_6, is less than vapor pressure, p_v; or more precisely, if local dynamic head is less than local total head minus vapor head, ie. $(P_6 - p_6) < (P_6 - p_v)$,

where $P_6 - p_6 = (Q/A_6)^2/2g$

and $P_6 - p_v = V_o^2/2g + H_a - P_{loss} - P_v$.

If this condition exists at the evaluated speed, an indication to that effect is printed in the program output.

Cavitation on the pump impeller is not intrinsically determined by the program, but the suction specific speed, S, at which the pump is operating at the evaluated speed is determined and printed out. The suction specific speed at which cavitation occurs may vary depending upon the pump design; but, by knowing the suction specific speed at which the pump is required to operate, the user can readily determine if the limiting value is exceeded. The suction specific speed at the evaluated condition is determined by

$$S = NQ^{\frac{1}{2}}/H_{sv}^{0.75}$$

where H_{sv}, the net positive suction head, is given by

$$H_{sv} = V_o^2/2g + H_a - p_v - P_{loss}.$$

3. DESIGN METHODOLOGY

The design methodology used in the design portion of the program is described in detail in references 1, 2, and 3, and is summarized here to lend continuity and completeness to this report.

The design routine uses a directed pattern search to select a system which is optimized from the standpoint of having the lowest overall system weight of any satisfactory system. The system weight includes all structural and machinery weight attributable to the propulsion system, as well as the weight of all water entrained in the system above the waterline and the weight of fuel required to provide the specified endurance at cruise speed. The craft displacement is held constant during the optimization routine, thus the selection of a minimum weight propulsion system maximizes the payload for that particular craft.

The variable parameters used in the design optimization are jet velocity ratio, V_j/V_o, inlet velocity ratio, V_i/V_o, and nacelle inlet to maximum diameter ratio, D_i/D_m. The pattern search subroutine selects different values of these parameters for each design iteration and retains the values which produced the minimum weight system. When the search pattern has been completed; V_j/V_o, V_i/V_o, and D_i/D_m are reset to the values corresponding to the minimum weight system and the design routine is entered for a final time in order to reproduce that system.

In addition to V_j/V_o, V_i/V_o, and D_i/D_m; the design routine requires that at least the following information be specified to define the craft for which the propulsion system is being designed:

a. Displacement

b. Range

c. Prime mover

d. Craft speed at take-off and cruise

e. Craft drag at take-off and cruise

f. Depth of submergence of foil

g. Distance of strut from transom

h. Distance of pump exit from transom

i. Height of pump centerline above waterline

The design routine begins by using the inlet and jet velocity ratios chosen by the pattern search subroutine, together with the specified craft speed, to calculate the required inlet and jet velocities at the cruise condition. The optimum nozzle depression angle is then determined by

$$\beta = \tan^{-1}(D_{total}/\Delta).$$

These values are then used to calculate the required flow rate and the required inlet and jet areas.

The design routine then proceeds to size the components of the system in the same sequence as previously described for the evaluation routine; and , after each component has been sized, losses and drags are determined in the same manner as in the evaluation routine.

The nacelle inlet to maximum diameter ratio, as selected by the pattern search subroutine, determines the amount of diffusion possible prior to the strut elbow. Since the inlet diameter has already been determined, the maximum diameter is therefore fixed by the diameter ratio. The length of the nacelle forebody is determined by selecting the length to maximum diameter ratio which is just at incipient cavitation on the external surface at cruise speed. The ratio of inlet to maximum diameter which corresponds to the forebody shape thus chosen is compared with that ratio previously specified. If the previously specified ratio exceeds the maximum ratio allowed by cavitation, the forebody is resized using the maximum allowable ratio. An iteration is then performed to determine the overall nacelle length which will result in the least total power loss due to external drag and diffusion in the ducting.

The inlet area of the strut elbow is set equal to the exit area of the nacelle diffuser. The elbow shape, radius ratio and bend angle are determined according to assumptions previously described for the evaluation routine. The number of splitters or guide vanes is then determined to minimize losses in the elbow.

The strut diffuser inlet area and shape is set equal to the exit of the strut elbow, and the diffuser area ratio is chosen to avoid cavitation in the pump inlet piping. The external surface of the strut is sized as necessary to enclose the ducting, and the shape is chosen to avoid external cavi-

tation.

The nacelle, strut and spray drags which have been calculated during this iteration are compared with previous estimates of these drags. If a significant difference exists, the drag estimates are revised and calculations begin anew; otherwise the rest of the system is then designed.

The hull elbow is designed in the same manner as the strut elbow, and the configuration of the pump inlet piping is selected according to the number of pumps. The pump inlet piping begins with a transition from the shape of the hull elbow to a circular shape, and the rest of the piping is circular is shape. The size of the pump inlet piping is chosen to maintain a constant velocity throughout its length.

The nozzle is assumed to have an inlet area equal to the pump outlet area. This and the jet area which has been previously determined are used to calculate losses in the nozzle.

The ducting losses prior to the pump are used to determine net positive suction head, and nozzle losses are added to determine the required pump head. Two basic pump designs are considered; axial with an inducer impeller, and centrifugal with double suction impellers. The alternative pumps are sized by using assumed specific speeds, flow coefficients and impeller diameter ratios for each alternative. The number of axial stages is determined by cavitation criteria, while the number of stages in the centrifugal pump is chosen to minimize combined pump, gear and fuel weight. The required gear ratio is determined

as the ratio of prime mover normal operating speed to required pump speed at take-off and this ratio, together with the required shaft horsepower at take-off, determines the type and size of gear to be used. The fuel weight required to provide the specified endurance at cruise speed is calculated for each alternative design, and that pump design which requires the lowest combined weight of pump, gear and fuel is then chosen as the pump to be used by the design.

4. DISCUSSION OF RESULTS

Sample outputs for both the evaluation and the design routine are contained in Appendix C. The format used for output from the evaluation routine is essentially the same as that used for design. This permits maximum compatibility within the output subroutine; and, additionally, facilitates comparison of data produced by the design routine with that produced by the evaluation routine for the same or any other system.

The design routine was analyzed for sensitivity of a basic design to variations in initial values of the independent variables and to variations in normally fixed parameters. The basic design used in the analysis was for a 750 ton hydrofoil with a take-off speed of 30 knots, a cruise speed of 45 knots, and an endurance of 2000 miles at cruise speed. Two LM2500 gas turbines were the specified prime movers, and the specified number of pumps was two.

In most cases there was little or no variation in the resulting system design when the starting values of the independent system parameters were varied. In some cases, however, significant variations occured with total system weight varying by as much as 3.5%. In those cases where results did vary, the jet velocity ratio of the resulting design deviated very little from that of the basic design. The inlet velocity ratio and nacelle diameter ratio both varied over a considerable range, however, consequently the changes in system weight resulted primarily from changes in the nacelle and strut designs. This suggests

that the optimum design is primarily defined by the jet velocity ratio and that the inlet velocity ratio and nacelle diameter ratio become important only after the optimum jet velocity ratio has been determined. This may also explain the apparent lack of correlation between inlet velocity ratio and other parameters in designs produced by the program. Further study of this problem is needed and it may be necessary to revise the design routine so that once an initial solution is obtained, the jet velocity ratio is fixed at the resulting value while further variations in the other two system parameters are explored.

The results showed a considerable sensitivity to variations in craft drag; particularly that component of drag which is not directly attributable to the propulsion system, referred to here as ship drag. Ship drag is a craft characteristic which is independent of the propulsion system design and it is held constant at the input value throughout the design calculations. Relatively small variations in ship drag produced comparatively large changes in total system weight. This sensitivity is apparently due to the fact that the cases studied for this report fall in a region where the selection of a system design is constrained by a power limitation imposed by the specified prime movers. If there were no power limitation, the optimum system would have a very high jet velocity ratio and consequently a low volume flow rate thereby reducing both ducting weight and the weight of entrained water. If take-off drag, and therefore the required take-off thrust, is so high that a power limita-

tion is imposed; then the jet velocity must be reduced in order to reduce the required pump head sufficiently to bring required power back within limits. The reduction in thrust due to the lowered jet velocity must then be compensated for by increasing the flow rate. This requires larger and heavier ducting and results in a larger volume of entrained water. This suggests that the optimum combination of craft and propulsion system would be one in which the propulsion system design selected by the design routine just bordered on being power limited.

In view of the above discussion, it appears that the propulsion coefficient based upon installed horsepower is an important system parameter since it is basically a measure of the fraction of installed horsepower required to overcome drag.

$$PC_i = (D_{total}V)/(550\ SHP_i)$$

The propulsion weight fraction and the propulsive coefficient based on used horsepower at cruise speed are plotted against the installed power propulsive coefficient at take-off in Figures 2 and 3 respectively. The curves are plotted for designs in which ship drag was the only parameter varied. The other points plotted represent designs in which other parameters were varied.

The results also showed some sensitivity to variations in the strut length. This was to be expected since reducing the strut length would reduce the required pump head as well as reducing the amount of ducting and entrained water in the system. The sensitivity was not nearly as pronounced as the sensitivity to ship drag.

The evaluation routine was tested by evaluating systems designed by the design routine at both design and off design speeds. The results were satisfactory and, when the evaluation conditions were the same as design conditions, the operational characteristics of the system as determined by the evaluation routine were nearly identical to those calculated by the design routine.

5. CONCLUSIONS AND RECOMMENDATIONS

A computer program to evaluate the performance of a waterjet propulsion system has been developed and incorporated into the program for design optimization of waterjet propulsion systems. The evaluation routine can be used successfully to evaluate a wide array of possible system configurations. A lack of available data on the configuration and performance of existing systems precluded the use of the evaluation routine to analyze the performance of an actual system for this report. When such information is available, it is recommended that this be done. The results obtained from the evaluation routine could then be compared with actual performance data to further evaluate the accuracy of the methods used in the program.

The sensitivity of the design routine to initial values of the independent variables requires further study. The use of either a random search or an additional pattern search is suggested to explore further variations in inlet velocity ratio and nacelle diameter ratio once the best jet velocity ratio has been determined in the manner currently used in the program.

The results of the design routine are highly sensitive to variations in ship drag when the available power is barely adequate for the design conditions. This indicates that the total hydrofoil design should be carefully tailored to the prime mover so that the total power required at design conditions is somewhat less than the total available power in order to allow for growth. If the hydrofoil is designed so that maximum

available horsepower is required at either take-off or cruise condition, the specified craft conditions must include an adequate margin for growth. If not, a serious degradation of performance would occur when the inevitable growth took place because, if maximum power is already being used, there would be no way of increasing available thrust to compensate for increased drag without exceeding the power limitations of the prime mover.

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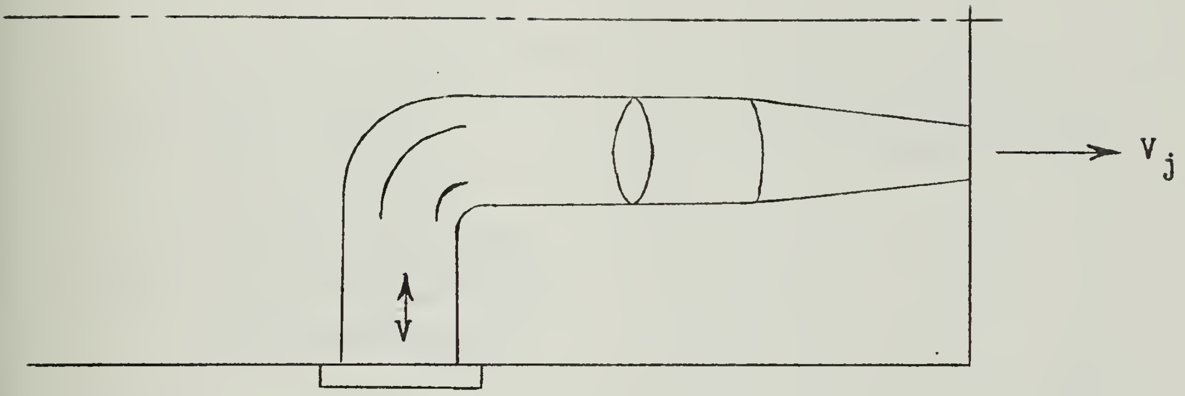
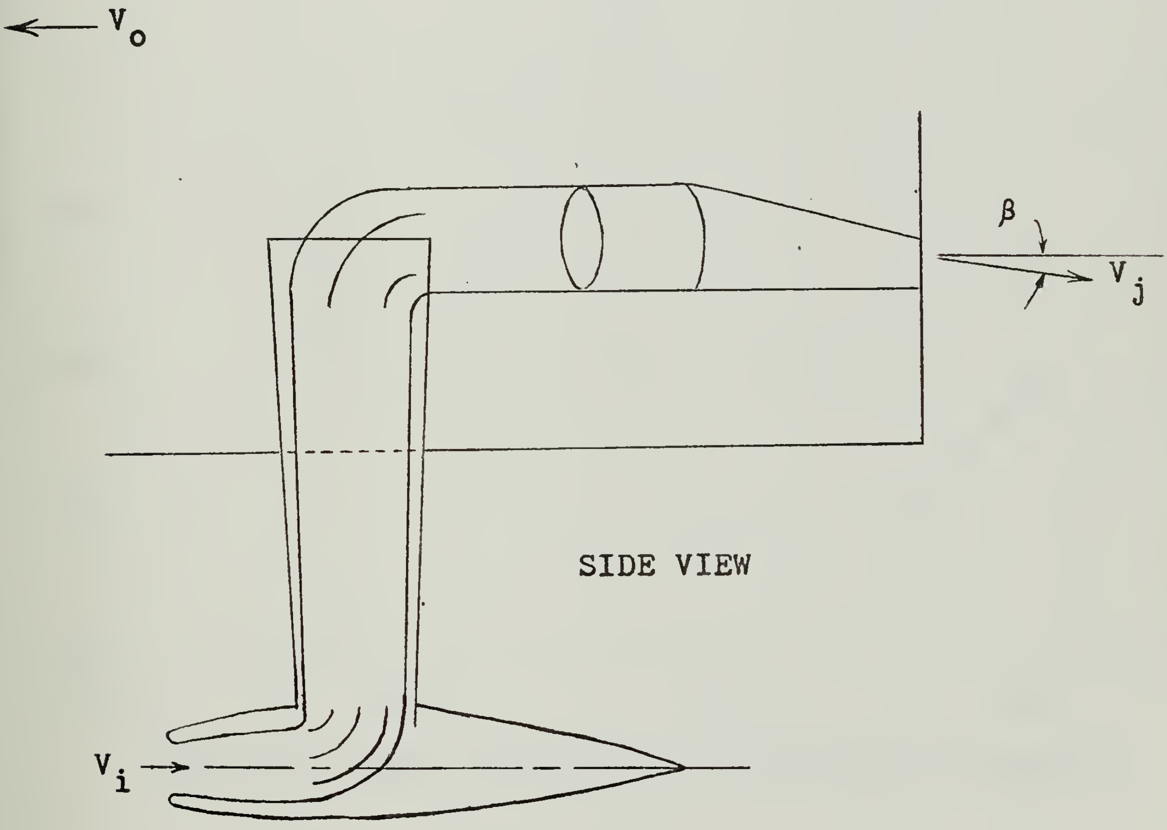


TOP VIEW



SIDE VIEW

FIGURE 1: GENERAL DUCTING CONFIGURATION

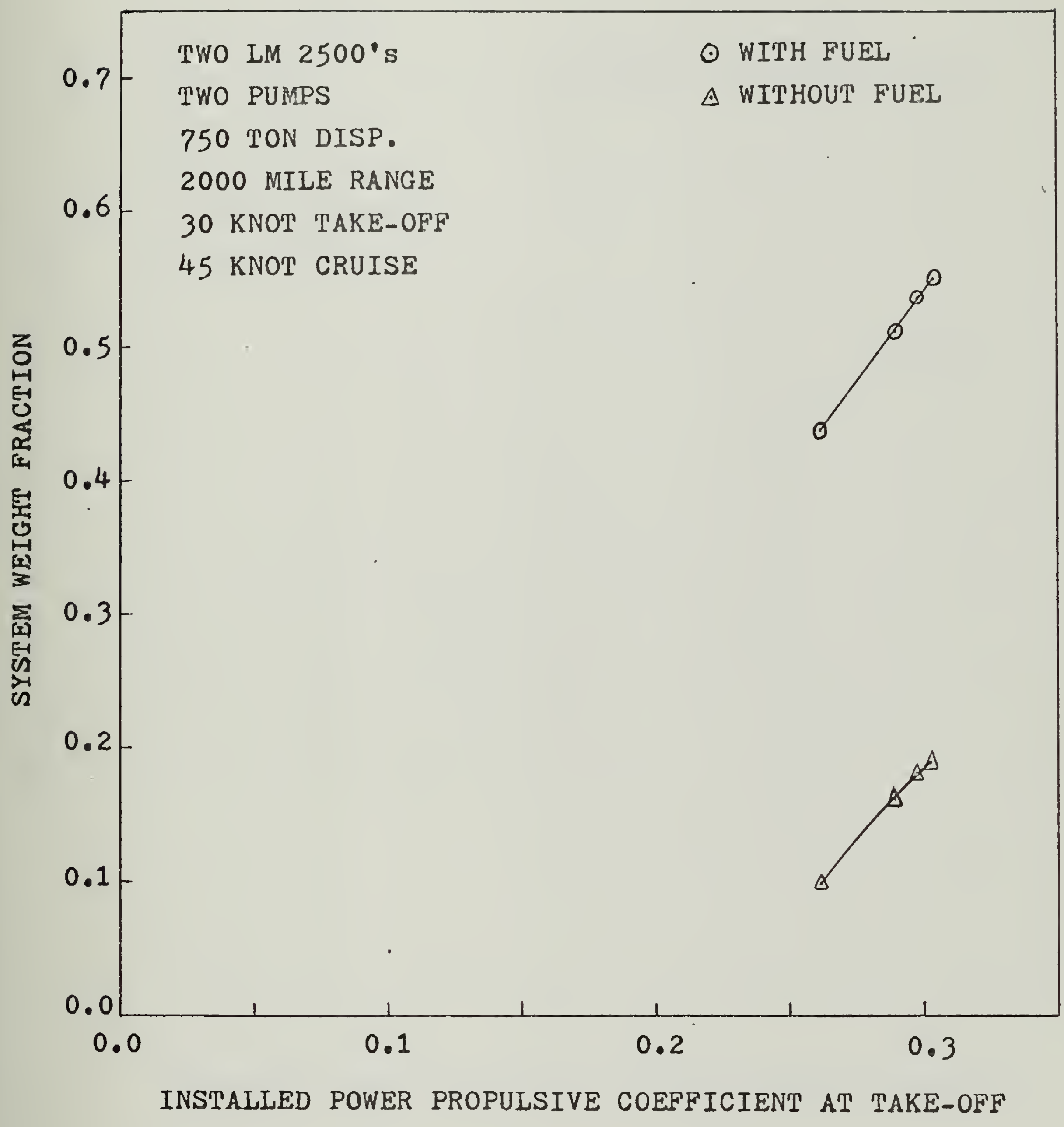


FIGURE 2: PROPULSION SYSTEM WEIGHT FRACTION VS. INSTALLED POWER PROPULSIVE COEFFICIENT AT TAKE-OFF

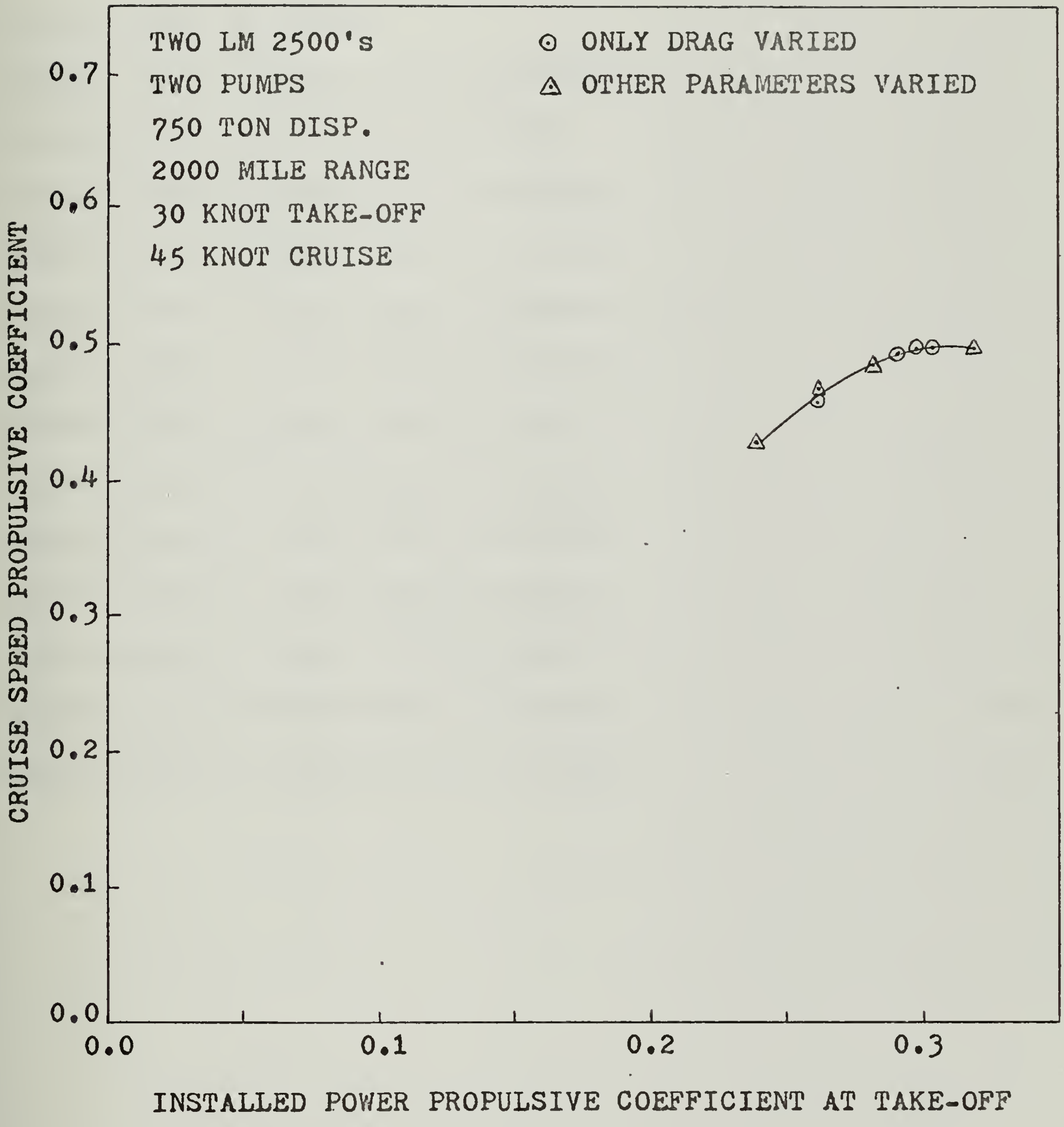


FIGURE 1: CRUISE SPEED PROPULSIVE COEFFICIENT VS. INSTALLED POWER PROPULSIVE COEFFICIENT AT TAKE-OFF

APPENDIX A

LIST OF SYMBOLS USED IN PROGRAM

SYMBOLS USED IN COMMON 43

SYMBOLS USED IN H2OJT NOT IN COMMON 56

SYMBOLS USED IN FCT NOT IN COMMON 58

SYMBOLS USED IN NACEL NOT IN COMMON 60

SYMBOLS USED IN ELBOW NOT IN COMMON 65

SYMBOLS USED IN STRUT NOT IN COMMON 67

SYMBOLS USED IN JUNCT NOT IN COMMON 69

SYMBOLS USED IN PIPE NOT IN COMMON 70

SYMBOLS USED IN DIVRG NOT IN COMMON 71

SYMBOLS USED IN NOZZL NOT IN COMMON 73

SYMBOLS USED IN PUMP NOT IN COMMON 74

SYMBOLS USED IN FUEL NOT IN COMMON 77

SYMBOLS USED IN PTTRN NOT IN COMMON 78

SYMBOLS USED IN OUTPUT NOT IN COMMON 79

LIST OF SYMBOLS

USED IN COMMON

Label	Variable Name	Subscript	Description/Usage
PARMS			System parameters
	VJVO		Jet velocity ratio
	VIVO		Inlet velocity ratio
	DIDM		Inlet diameter to maximum nacelle diameter ratio
DRAG			Drag estimates
	TDRAG(I)	I	Total craft drag at condition I, pound force
		1	Cruise condition
		2	Take-off condition
		3-5	Evaluation conditions
	STRTD(I)		Strut drag at condition I, pound force
	POD(I)		Nacelle drag at condition I, pound force
	SPRAY(I)		Spray drag at condition I, pound force
	REST(I)		TDRAG(I)-SPRAY(I)-STRTD(I) -POD(I),pound force
	VO(I)		Craft velocity at condition I, foot per second
	TRIM(I)		Craft trim angle at condition I, degree
FLOW			Flow characteristics
	Q(I)		Volume flow rate at condition I, cubic foot per second

Label	Variable Name	Subscript	Description/Usage
	AIN		Inlet area, square foot
	AJET		Jet area, square foot
	AREA(ICOMP)		Ducting cross-sectional area at station ICOMP, square foot
	VJ(I)		Jet velocity at condition I, foot per second
	VI(I)		Inlet velocity at condition I, foot per second
ELBW			Elbow data
	XK(IELB)	IELB	Radius ratio of elbow IELB
		1	Strut elbow
		2	Hull elbow
		3	Pump elbow
		4	Divergence elbow
	RO(IELB)		Duct radius at elbow IELB, degree
	THATA(IELB)		Angle of bend of elbow IELB, foot
	WIDTH		Width of duct at elbow inlet
	DEPTH		Depth of duct at elbow inlet
	TYPE(3,ITYPE)		Contains name of elbow shape ITYPE
CHARS			System characteristics
	WGTS(LS,LC)		Weight of component LC, pound

Label	Variable Name	Subscript	Description/Usage
		LS	
		1	Structure
		2	Water (or fuel)
		LC	
		1	Nacelle
		2	Strut elbow
		3	Strut diffuser
		4	Hull elbow
		5	Athwartships length
		6	Pump elbow
		7	Transition piece
		8	Pump
		9	Nozzle
		10	Reduction gear
		11	Fuel
		12	Prime mover
		13	Lift from nozzle depression
		14	Total weight
		15	Spare location
	CGS(LG,LC)		Centers of gravity of component LC, excluding fuel, gearbox, or prime mover, foot
		LG	
		1	Structure vertical center of gravity (from keel)

Label	Variable Name	Subscript	Description/Usage
		2	Structure longitudinal center of gravity (from transom)
		3	Water vertical center of gravity, (from keel)
		4	Water longitudinal center of gravity, (from transom)
	DELH(I,ICOMP)		Total head loss up to and including component ICOMP at condition I, foot
		ICOMP	Same as defined except
		8	Nozzle head loss only
		9	Total system head loss (including elevation), DELH(I,9)=DELH(I,8)+ DELH(I,7)
		10-15	Spare locations
	CGSX		Total longitudinal center of gravity system excluding gearbox, prime mover and fuel, from transom, foot
	CGSZ		Total vertical center of gravity of system excluding gearbox, prime mover and fuel, from keel, foot
H2O			Sea water (3.5% salinity) properties
	TEMP		Temperature, degree Fahrenheit
	PV		Vapor head, foot
	RHOW		Density, pound force second squared per foot to the fourth

Label	Variable Name	Subscript	Description/Usage
	GNU		Viscosity, foot squared per second
	HA		Atmospheric head, foot
TOLER			
	DELTA		Check for optimum system
PSUB			Pump system
	GERAT(NSTG)		Gear ratio required for pump NSTG
	SHP(I,NSTG)		Shaft horsepower per prime mover required at condition I for pump NSTG, horsepower
	RPM(I,NSTG)		Axial speed of pump NSTG at condition I, revolution per minute
	PERF(L,IENGN)		Prime mover IENGN Characteristics (L)
		L	
		1	Maximum normal horsepower at design speed, horsepower
		2	Maximum intermittent horsepower at design speed, horsepower
		3	Specific fuel consumption (SFC) at design speed and maximum normal horsepower, pound fuel per horsepower hour
		4	Design speed, RPM
		5	Prime mover weight, without auxiliaries, pound
	ETAP(I,NSTG)		Efficiency of pump NSTG at condition I

Label	Variable Name	Subscript	Description/Usage
		I	Same as defined except
		7	Reduction gear
		6,8	Spare locations
SHIP			Craft characteristics
	DISP		Craft displacement, pound
	RANGE		Endurance, nautical mile
	BEAM		Beam, foot
	HS		Depth of submergence of foil, foot
	HE		Height of pump centerline above mean water, foot
	HCL		Height of pump centerline above keel, foot
	XLS		Distance of centerline of strut root from transom, foot
	XLPE		Distance of pump exit from transom, foot
	XLP		Length of pump, foot
NACLL			Nacelle characteristics
	DRAT		Diameter ratio, DI/DM
	DM		Maximum external diameter, foot
	AI		Inlet area per nacelle, square foot
	AIAUX		Auxiliary inlet area per nacelle, square foot
	ELEXT		Length of forebody, foot
	ELENT		Length of lip, foot

Label	Variable Name	Subscript	Description/Usage
	ELAUX		Length due to auxiliary inlet, foot
	ELDIF		Length of diffuser, foot
	ELN		Length of nacelle, foot
	AAX(I)		Portion of auxiliary inlet area in use at condition I, square foot
CONST			Constants
	PI		3.14159265
	G		Acceleration of gravity, 32.174, foot per second squared
	RHOD		Density of steel, 480, pound per cubic foot
STRTC			Strut characteristics
	TC		Thickness to chord ratio
	T		Thickness at root, foot
	C		Chord at root, foot
	T1		Thickness at tip, foot
	C1		Chord at tip, foot
	CFM		Chord at flying waterline, foot
INDEX			Indices for program control
	IEVAL		Design/evaluation index
		<0	Evaluate at IEVAL points, no design
		=0	Design at cruise and takeoff conditions only

Label	Variable Name	Subscript	Description/Usage
		>0	Design at cruise and take-off conditions and evaluate at IEVAL points
	IEQPT		
		0	No equipments or configuration entered; total system design/evaluation
		1	Number of gas turbines is specified
		3	Number of gas turbines and number of pumps are specified
	ISTRT		Initial program condition
		1	Design and/or evaluate
		3	Evaluate only
	NUMB		Final program condition
		2	Design only
		2+|IEVAL|	Design and/or evaluate
	IENGN		Prime mover type
		1	TF 35
		2	TF 40
		3	Proteus, 1500 rpm
		4	Proteus, 1000 rpm
		5	Tyne 1A
		6	Tyne 1C
		7	FT12A
		8	LM 1500
		9	LM 2500
		10	FT4A-2C

Label	Variable Name	Subscript	Description/Usage
		11	FT4A-12
		12	FT4C-2
	ITYPE		Elbow shape
		1	Ellipse
		2	Circle
		3	Rectangle
		4	Square
	ICOMP		Component index
		1	Nacelle outlet
		2	Strut elbow
		3	Strut diffuser exit
		4	Hull elbow
		5	Athwartships length
		6	Pump elbow
		7	Transition piece
		8	Pump inlet
		9	Nozzle throat
	NPUMP		Number of pumps
	NGT		Number of gas turbines
	IGEAR		Type of reduction gear
		1	Single reduction with idler
		2	Planetary
		3	Double reduction, double branch
ITABL			Interpolation parameters

Label	Variable Names	Subscript	Description/Usage
CDRAG			Computed drags
	CSTRT(I)		Computed strut drag at condition I, pound force
	CPOD(I)		Computed nacelle drag at condition I, pound force
	CSPRY(I)		Computed spray drag at condition I, pound force
WEGT			Pump, gear and fuel weights
	XWD(NSTG)		Pump NSTG dry weight, pound
	XWW(NSTG)		Pump NSTG wet weight, pound
	XWG(NSTG)		Gearbox weight associated with pump NSTG, pound
	XWF(NSTG)		Fuel weight associated with pump NSTG, pound
PUMM			Pump characteristics
	QQ(I)		Flow rate per pump at condition I, cubic foot per second
	D1S(NSTG)		Inlet tip diameter of pump NSTG, foot
	D2S(NSTG)		Exit tip diameter of pump NSTG, foot
	XNS(NSTG)		Specific speed of pump NSTG, cfs units
	SM(I,NSTG)		Suction specific speed of pump NSTG at condition I, cfs units
	PLP(NSTG)		Length of pump NSTG, foot
	NSTG		Indicator of pump type
		1	Axial pump with single inducer impeller

Label	Variable Name	Subscript	Description/Usage
		2	Axial pump with inducer and one impeller stage
		3	Axial pump with inducer and two impeller stages
		4	Centrifugal pump with maximum of ten parallel double suction impellers
		5	Spare location
	SHI(I,NSTG)		Head coefficient of pump NSTG at condition I
	XIM		Number of parallel double suction impellers for centrifugal pump
			Number of impellers, not including inducer, for centrifugal pump
HEAD			Pump flow characteristics
	HPP(I)		Pump head at condition I, foot
	HSV(I)		Net positive suction head at condition I, foot
	THOM(I)		Thoma's cavitation index at condition I
	PHI(I,NSTG)		Flow coefficient of pump NSTG at condition I
	WF		Working variable for fuel weight, pound
	WG		Working variable for gear weight, pound
	FRATE(I)		Fuel consumption rate at condition I, pounds per hour
PINLP			Pump inlet piping parameters

Label	Variable Name	Subscript	Description/Usage
	ALPHA		Junction angle
WARN			Warning generated during evaluation
	CAV(I,J)	J	Cavitation indicator at condition I at location J
		1	Nacelle exterior
		2	Strut exterior
		3	Nacelle inlet lip
		4	Strut elbow
		5	Pump inlet
		6	Pump impeller
NOZL			Nozzle characteristics
	JANGL		Nozzle depression angle
	*****		Unlabeled common variables
	IFUEL		Logical variable for fuel calculation
		.TRUE.	Make fuel calculation
		.FALSE.	Do not make fuel calculation
	IPUMP		Logical variable for pump calculation
		.TRUE.	Pump design parameters have been calculated/specified
		.FALSE.	Pump design parameters have not been calculated/specified
	TYGER		Logical variable for gear calculation
		.TRUE.	Gear type is specified

Label	Variable Name	Subscript	Description/Usage
		.FALSE.	Gear type is to be selected by program

VARIABLES USED IN H2OJT
NOT IN COMMON

Variable	Description
PARM(3)	Working system parameters
ENGN(3,IEGN)	Contains name of engine IENGN for output
EHP(I)	Effective horsepower at condition I, horsepower
DEL(3)	Initial step sizes of system parameters
DELMIN(3)	Minimum step sizes of system parameters
VK(I)	Craft speed at condition I, knot
IPRNT	Print data set reference number
DISPL	Craft displacement, long ton
IN	Estimate of minimum number of gas turbines required to power craft
MAX	Estimate of maximum number of gas turbines needed to power craft
XJ	Working variable for number of gas turbines
IK	Working variable for craft condition I
IL	Working variable for IN
KM	Minimum number of pumps to be used for XJ gas turbines
K1	Maximum numberof pumps to be used for XJ gas turbines
WEIGT	Propulsion system weight, long ton
IM	Working variable for prime mover characteristic L
DISPL	Craft displacement, long ton
I	Index for do loops
IJ	Working variable for check on power adequacy
J	Index for do loop

Variable	Description
ISAVE	Working variable for MAX
N	Working variable for output of prime mover type
XMIN	Factor for minimum acceptable prime mover SHP operation
MK	Working variable for prime mover characteristic L
JNUM	Working variable for NUMB

LIST OF VARIABLES USED IN FCT NOT IN COMMON

Variable		Description
APOD(I)		Difference between present and previous nacelle drag calculations at conditions I, pound force
ASTRT(I)		Difference between present and previous strut drag calculations at condition I, pound force
ASPRY(I)		Difference between present and previous spray drag calculations at condition I, pound force
C(I)		Margin factor for thrust at condition I
TSUM		Working variable for propulsion system weight, pound
DSIG		Working variable for SIGMA
TOTAL		Total head less vapor head, foot
SIGMA		Head above vapor head, foot
SUMZ		Working variable for moment in vertical plane, due to weights, foot pound force
SUMX		Working variable for moment on longitudinal plane due to weights, foot pound force
SUM		Working variable for system weights, pound
ZSUM		Total moment in vertical plane due to weights, foot pound force
XSUM		Total moment on longitudinal plane due to weights, foot pound force
SPD		Working variable for jet velocity calculation, foot per second
J		Working variable for NUMB
JDRAG		Indicator of acceptable drag accuracy
	1	New drag calculation is within 5% of previous calculation
	2	New drag calculation is greater than 5% of previous calculation, redesign strut and nacelle

Variable		Description
ANGLE		Optimum nozzle depression angle, radian
COEF		Factor for nacelle drag calculation
	0	Strut must be resized due to cavitation
	1	Use nacelle design
KOUNT		Working variable for craft condition I
I		Craft condition
PARM(K)		Working variable for system parameters
	K	
	1	VJVO
	2	VIVO
DDRAG(I)		Previous acceptable total drag calculation at condition I, pound force
DSPRY(I)		Previous acceptable spray drag calculation at condition I, pound force
DSTRT(I)		Previous acceptable strut drag calculation at condition I, pound force
DPOD(I)		Previous acceptable nacelle drag calculation at condition I, pound force

LIST OF VARIABLES USED IN NACEL NOT IN COMMON

Variable	Description
ZK	Percentage of auxiliary inlet area permitting flow
SPO	Static pressure at inlet, pound per square foot
PVP	Vapor pressure, pound per square foot
SIGTV	Incipient turning vane cavitation number, referenced to diffuser exit velocity
JNUMB	Working variable for NUMB
I	Craft condition, also index for do loops
CPEX	Peak external pressure coefficient
K	Working index for do loop for ELEXT/DM values
J	Working index for do loop for VIVO values
XD	Length of forebody to maximum diameter ratio, ELEXT/DM
DIDMX	Maximum permissible diameter ratio
QI	Flow rate per strut, cubic foot per second
DI	Nacelle inlet diameter, foot
CPIN	Peak internal pressure coefficient
QIN	Take-off flow rate per nacelle through inlet, cubic foot per second
QC	Take-off flow rate per nacelle, total, cubic foot per second
QAUX	Auxiliary flow rate required to avoid cavitation, cubic foot per second
KDEX	Counter for iterations on diffuser length
VR	Velocity ratio at take-off condition, based on flow through inlet
KNUMB	Working variable for NUMB

Variable	Description
VIJ	Inlet velocity at evaluation condition, based on flow through inlet
PRLJ	Pressure recovery coefficient of lip at evaluation condition
VI2	Inlet velocity at take-off condition, based on flow through inlet
PRL2	Pressure recovery coefficient of lip at take-off
PTI	Inlet stagnation pressure immediately aft of lip at take-off, pound per square foot
SPI	Inlet static pressure immediately aft of lip at take-off, pound per square foot
VIAUX	Inlet velocity in auxiliary inlet, foot per second
PRAUX	Pressure recovery of auxiliary inlet
PTAUX	Stagnation pressure inside auxiliary inlet, pound per square foot
DYP	Net dynamic pressure immediately aft of lip, pound per square foot
PC	Average inlet stagnation pressure of combined flow, pound per square foot
QDIF	Working variable for diffuser flow rate, cubic foot per second
PHI	Equivalent angle of forebody, radian
PHS	Sine of equivalent angle of forebody
X	Length of auxiliary inlet, foot
D2	Diffuser exit diameter, foot
D1	Inlet diameter, foot
ELMAX	Maximum permissible length of diffuser, foot
ELMIM	Minimum permissible length of diffuser, foot
II	Working variable for craft condition I

Variable	Description
EL	Working variable for diffuser length, foot
DEL	Working variable for change in diffuser length, foot
ELD	Working variable for nacelle length, foot
ELL	Working variable for nacelle length, foot
ELFAC	Working variable for excess in nacelle length due to diffuser, foot
DDM	Average diffuser diameter, foot
XKT	Form loss coefficient of diffuser
REL	Reynolds number, based on nacelle length
RED	Reynolds number, based on inlet diameter
DL	Ratio of maximum external diameter to nacelle length
CDRG	Computed drag coefficient
ANGL	Equivalent half angle of diffuser, degree
CDIF	Diffuser expansion factor
POW	Power loss due to drag and duct loss of diffuser, horsepower
POWI	Previous power loss calculation for diffuser length, horsepower
EM	Factor in wetted surface calculation
AEXN	Wetted surface area, square foot
REND	Reynolds number, based on inlet diameter
DDIF	Total pressure loss in diffuser, pound per square foot
PLOSS	Total pressure loss in nacelle, pound per square foot
VAOUT	Average exit velocity, foot per second
SQUAR	Factor in critical velocity calculation

Variable	Description
VCRIT	Critical velocity in strut elbow, foot per second
VMAX	Maximum velocity at nacelle exit, foot per second
RENL	Reynolds number, based on nacelle length
NL(2)	Interpolation parameters
ML(2)	Interpolation parameters
KL(2)	Interpolation parameters
JL(2)	Interpolation parameters
IL(2)	Interpolation parameters
VRT(6)	Data array of velocity ratios
XDT(10)	Tabulated forebody length to inlet diameter ratios
PRLT(6)	Tabulated lip pressure recovery coefficients
SIGI(I)	Free stream cavitation index at condition I
PTO(I)	Stagnation pressure at craft condition I, pound per square foot
XDTT(J)	Tabulated ELEXT/DM ratios for trim angle J
CDUMX(K)	Dummy array of peak pressure coefficients for VIVO K
CDUMY(L)	Dummy array of velocity ratios for ELEXT/DM L
CD(I)	Drag coefficients at craft condition I
DIDMT(J)	Tabulated DI/DM values for ELEXT/DM J
VRTT(J)	Dummy array of velocity ratios for angle of attack (J), internal
DLIP(I)	Lip loss coefficient at craft condition I
QO(I)	Free stream dynamic pressure at craft condition I, pound per square foot
VELR(I)	Inlet velocity ratio at craft condition I

Variable	Description
TLIP(I)	Working variable for DLIP(I)
VRTEX(I)	Same as VRTT(I) but external
VRMAX(I)	Maximum permissible velocity ratio at craft condition I
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

VARIABLES USED IN ELBOW NOT IN COMMON

Variable		Description
SHAPE(3,ITYPE)		Contains name of shape ITYPE
THETA(J)		Data array of elbow angles
XLOSS(J)		Data array of elbow loss coefficients with thin, circular arc turning vanes
ROA(10)		Outside radius of splitters, foot
RE		Reynolds number of duct
FRICT		Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number
CORR		Function statement, calculates head loss correction factor for different Reynolds numbers
REMAX		Maximum Reynolds number permitted for splitter loss equation
KOUNT		Working variable for craft condition I
IELB		Index indicating which elbow is being designed/evaluated
	1	Strut
	2	Hull
	3	Pump
	4	Divergence
FACTR		Factor used in splitter loss calculation
RIN		Inside radius of bend, foot
ROUT		Outside radius of bend, foot
RATIO		Desired radius ratio, 4.3
XN		Number of subdivided elbows required to achieve RATIO=4.3
N		Number of subdivided elbows used

Variable	Description
N1	Number of splitters corresponding to N
SUM	Working variable of sum of head times subdivided elbow area, foot cubed
RIA	Inside radius of subdivided elbow, foot
V	Average velocity, foot per second
HGT	Height of subdivided elbow, foot
AA	Equivalent cross-sectional area of subdivided elbow based on HGT, square foot
RAD	Equivalent radius of subdivided elbow, foot
XCORR	Ratio of head loss correction factors for differing Reynolds numbers
XKT	Head loss coefficient of subdivided elbow
DIAM	Equivalent diameter, foot
VOLV	Volume of splitters, cubic foot
VOL	Volume of splitters and elbow structure, cubic foot
AREA1	Duct area per elbow, square foot
IJ	Working variable for shape determination
IK	Working variable for shape determination
I	Working variable for number of subdivided elbows N
RATEO	Ratio of inside radius to outside radius of subdivided elbows
HEAD	Average head loss in elbow, foot

LIST OF VARIABLES USED IN STRUT NOT IN COMMON

Variable	Description
THET2	Array of data of equivalent angle of diffuser, degree
EXPAN	Array of data of expansion coefficient
ARATO	Area ratio of strut diffuser
VL	Local maximum velocity, external, foot per second
SIGMA	Local cavitation number, external
SIGMI	Incipient cavitation number, external
CM	Mean chord, foot
DEIN	Strut inlet equivalent diameter, foot
WIDE	Width of duct at strut exit, foot
DEOUT	Strut exit equivalent diameter, foot
DEAVE	Average equivalent diameter, foot
STRT	Vertical strut length, foot
XLONG	Actual strut length, foot
STAN	Arctangent of equivalent diffuser angle
THETA	Equivalent angle of diffuser, 2θ, degree
ECOEF	Diffuser expansion factor
FORML	Diffuser expansion loss coefficient
VELIN	Average inlet velocity, foot per second
VLOUT	Average exit velocity, foot per second
RES	Strut Reynolds number, based on mean chord
CDS	Strut drag coefficient
CDSP	Spray drag coefficient
RE	Duct Reynolds number, based on inlet velocity

Variable	Description
PIPEL	Duct friction loss coefficient
TOTAL	Total loss coefficient
HEAD	Head loss of diffuser, foot
KOUNT	Working variable for craft condition I
HGT	Elevation of strut, foot
CGWS	Vertical center of gravity of duct, foot

LIST OF VARIABLES USED IN JUNCT NOT IN COMMON

Variable	Description
DIAM	Duct diameter, foot
FRCTL	Friction loss coefficient for athwartships length
KOUNT	Working variable for craft condition I
AJCT	Length of fore and aft ducting to pump inlet, foot
FRCTJ	Friction loss coefficient for junction
XLAMD	Working variable for AMIXL calculation
FLONG	Length of athwartships ducting, foot
AJCTL	Total loss coefficient of junction
AMIXL	Mixing loss coefficient of junction
V	Average velocity, foot per second
XPUMP	Number of gas turbines + 1
RE	Reynolds number of duct
BETA(J)	Data array of junction angles, degree
ALAMD(J)	Data array of mixing loss coefficient corresponding to BETA(J)
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

LIST OF VARIABLES USED IN PIPE NOT IN COMMON

Variable	Description
KOUNT	Working variable for craft condition I
V	Average velocity, foot per second
DIAM	Duct diameter, foot
RE	Reynolds number of duct
APIPE	Length of fore and aft pipe to pump inlet, foot
FRCTL	Friction loss coefficient for athwartships length
XPUMP	Number of gas turbines
XKT	Friction loss coefficient of fore and aft length
XLONG	Length of athwartships pipe, foot
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

LIST OF VARIABLES USED IN DIVRG
NOT IN COMMON

Variable	Description
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number
KOUNT	Working variable for craft condition I
RE	Reynolds number of duct
DIVL	Divergence loss coefficient, not including friction
DWGT1	Duct weight of divergence angle, pound
DWGT2	Duct weight of divergence length, pound
DWGT3	Duct weight of pump inlet angle, pound
WWGT1	Water weight of divergence angle, pound
WWGT2	Water weight of divergence length, pound
WWGT3	Water weight of pump inlet angle, pound
CGWX1	Longitudinal center of gravity of divergence angle, from transom, foot
CGWX2	Longitudinal center of gravity of divergence length, from transom, foot
CGWX3	Longitudinal center of gravity of pump inlet angle, from transom, foot
DIAM	Duct diameter, foot
FRCTL	Friction loss coefficient for athwartships length
DIVLC	Total divergence loss coefficient
XPUMP	Number of gas turbines + 1
ANGLE	Divergence angle, also pump inlet angle, radian
HEADL	Total divergence head loss, foot
FLONG	Athwartships length, foot

Variable	Description
XLONG	Fore and aft length, foot
V	Average velocity, foot per second
ADIV	Divergence length, ADIV = XLONG/COS(ANGLE), foot
THETA(J)	Data array of divergence angles, degree
COEF(J)	Data array of divergence loss coefficients without friction, corresponding to THETA(J)

LIST OF VARIABLES USED IN NOZZL NOT IN COMMON

Variable	Description
KOUNT	Working variable fro craft condition I
XLPS	Dummy nozzle length, foot
XFAC	Check on whether nozzle exits through bottom or stern
XPUMP	Number of pumps
ANOZ	Optimum nozzle depression angle, radian
XLNOZ	Nozzle length, foot
DT	Nozzle throat diameter, foot
DJ	Nozzle jet diameter, foot
XCORR	Nozzle head loss factor
RE	Reynolds number, based on average diameter and velocity
AREA1	Throat pipe area, square foot
AJET1	Jet pipe area, square foot
QQ	Flow rate per nozzle, cubic foot per second
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

LIST OF VARIABLES USED IN PUMP NOT IN COMMON

Variable	Description
K	Cruise condition indicator
J	Take-off condition indicator
I	Index for do loops
XPUMP	Number of pumps
THOMI	Lower limit of Thoma's criterion for single inducer axial pump
DRAT	Hub to tip diameter ratio
XXLP	Factor for pump length
CW	Weight coefficient
QX	Ratio of cruise flow rate to take-off flow rate
CA	Factor for RPM calculation
CB	Factor for RPM calculation
HX	Ratio of design pump head to off design head
RX	Ratio of design to off design pump RPM
PHRAT	Ratio of off design to design flow coefficients
XNGT	Number of gas turbines
ETAPP	Product of pump and gearbox efficiencies
HP	Inducer head for one and two stage axial pump designs, foot
THOMS	Thoma's cavitation criterion for inlet to axial stage
HHP	Axial stage pump head, foot
BETA2	Exit blade angle, radian
JNUMB	Working variable for numb
ETAX	Ratio of off design to design pump efficiency

Variable	Description
XNNS	Non-dimensional specific speed
BD	Impeller exit width ratio
CC	Factor in flow coefficiect calculation
AA	Factor in flow coefficient calculation
IMPL	Maximum number of impellers permitted for centrifugal pump, = 10
M	Working variable for number of centrifugal pump impellers
N	Working variable for NSTG
PC(K,J)	Inducer head curve coefficients
PCA(K,J)	Inducer plus axial stage head curve coefficients
PCC(K,J)	Centrifugal pump head curve coefficients
XRPM(M)	Working variable for off design RPM of centrifugal pump with M impellers, RPM
XD1(M)	Working variable for inlet tip diameter, D1S, foot
RPK(M)	Working variable for design RPM of centrifugal pump with M impellers, square foot
XPUP(M)	Working variable for centrifugal pump area with M impellers, foot squared
YLP(M)	Working variable for centrifugal pump length with M impellers, foot
XERAT(M)	Working variable for gear ratio required for centrifugal pump with M impellers
APUP(NSTG)	Inlet area of pump NSTG, square foot
WRAT(NSTG)	Weight ratio of pump NSTG, including pump dry and wet weight, gearbox and fuel
WD(M)	Working variable for XWD(NSTG) for centrifugal pump with M impellers
WW(M)	Working variable for XWW(NSTG) for centrifugal pump with M impellers

Variable	Description
WWG(M)	Working variable for XWG(NSTG) for centrifugal pump with M impellers
QQ(I)	Flow rate per pump at condition I, cubic feet per second

LIST OF VARIABLES USED IN FUEL
NOT IN COMMON

Variables	Description
CFS	Constant for SFC calculation
CA	Cruise condition drag to lift ratio
CD	1 + total system head loss coefficient, based on jet velocity
N	Number of intervals endurance is divided into + 1
XN	Number of intervals endurance is divided into
TI	Time to cover one range interval at constant VO(1), hour
IJK	Index for shifting SFC curves
XJ	Factor to convert SFC if SHP is less than 70% of design SHP
I	Working index for N
H	Head required, foot
SHPP	Total thrust required, horsepower
SHNG	Total thrust required per engine, horsepower
M	Working index for N
WT(ITIME)	Weight of fuel used in time increment ITIME, pound
DIS(ITIME)	Displacement at time increment ITIME, pound
VJJ(ITIME)	Jet velocity at time increment ITIME, foot per second
ENN	Working variable for XJ

LIST OF VARIABLES USED IN PTTRN NOT IN COMMON

Variable	Description
PSI(N)	Current basepoint coordinate of parameter N
THETA(N)	Previous basepoint coordinate of parameter N
PHI(N)	Present exploratory point coordinate of parameter N
DEL(N)	Current step size of parameter N
DELMIN(N)	Minimum step size of parameter N
DIR(N)	Last successful direction of parameter N
SAVE(N)	Working variable for PHI(N)
S	Working variable for function value
SPHI	Working variable for function value at PHI coordinates
SPSI	Current best function value at PSI coordinates
NUMB	Counter for minimum step size check
RHO	Step size change factor
ICALL	Indicator of current point move
K	Index for do loop
I	Index for do loop
N	Number of parameters of search
SIGN(N)	Directed step size of parameter N

LIST OF VARIABLES USED IN OUTPUT NOT IN COMMON

Variable	Description
IPRNT	Print data set reference number
J	Working variable for condition I
SUM	Total duct head loss, excluding elevation, foot
I	Index for do loop
DRATO	Strut diffuser area ratio
IK	Index for number of elbows in system
XNGT	Number of gas turbines
K	Index for do loop
L	Index for implied do loop in output statement
LL	Working variable to point to correct head loss for output
KLL	Working variable to point to correct format statement for head loss output
M	Index for implied do loop in output statement
NIMP	Number of impellers in pump
TFM	Strut thickness at flying waterline, foot
WTRAT	Total propulsion system weight ratio
WRATF	Propulsion system weight ratio, excluding fuel
ENGN(IENGN)	Contains name of engine IENGN
VJRAT(I)	Jet velocity ratio at craft condition I
VIRAT(I)	Inlet velocity ratio at craft condition I
HEADL(I,ICOMP)	Head loss of component ICOMP at craft condition I
CONDS(2,I)	Label for craft condition I
ELBWS(2,IK)	Label for elbow IK

Variable	Description
PC(I)	Propulsive coefficient at craft condition I
LABEL(5,M)	Labels for output
VK(I)	Craft speed at condition I, knots
LOCAT(6,J)	Labels for cavitation locations

APPENDIX B

PROGRAM LISTING

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SUBROUTINE H2OJT 84

SUBROUTINE FCT 92

SUBROUTINE ELBOW 97

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SUBROUTINE STRUT 106

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SUBROUTINE GEAR 133

SUBROUTINE FUEL 136

SUBROUTINE NACEL 138

SUBROUTINE PTTRN 149

SUBROUTINE OUTPUT 153

BLOCK DATA 160

Note: Statement numbers in right hand margin indicate statements retained from design program listed in reference 1.

```
      LOGICAL IFUEL,IPUMP,TYGER
      REAL JANGL
      COMMON /PINLP/ALPHA
      COMMON /PARMS/VJVO,VIVO,DIDM
      COMMON /WARN/CAV(5,6)
      COMMON /NOZL/JANGL
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),
     1 TRIM(5)
      COMMON /NACLL/CRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN,AAX(5)
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
      COMMON /CONST/PI,G,RHOD
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /ITABL/L(2)
      COMMON IFUEL,IPUMP,TYGER
C
C     SAMPLE INPUT
C
      VO(1)=45.*1.6889
      VO(2)=30.*1.6889
      BEAM=36.
      RANGE=2000.
      HE=35.5
      HS=12.
      XLPE=12.
      IENGN=9
      XLS=32.
      HCL=17.5
      TRIM(1)=0.
      TRIM(2)=0.
      TYGER=.FALSE.
      DISP=750.*2240.
```

```
POD(1)=11436.1
STRTD(1)=11653.7
SPRAY(1)=8474.2
POD(2)=POD(1)*(VO(2)/VO(1))**2
STRTD(2)=STRTD(1)*(VO(2)/VO(1))**2
SPRAY(2)=SPRAY(1)*(VO(2)/VO(1))**2
REST(1)=76956.
REST(2)=129971.6
CALL H2OJT
STOP                                                                      0034
END                                                                       0035
```

```
      SUBROUTINE H2OJT                                                  H2OJ0001
      LOGICAL IFUEL,IPUMP,TYGER
      REAL JANGL
      COMMON /PINLP/ALPHA
      COMMON /NOZL/JANGL
      COMMON /WARN/CAV(5,6)
      COMMON /PARMS/ VJVO,VIVO,DIDM                                     H2OJ0003
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),     H2OJ0004
     1 TRIM(5)                                                          H2OJ0005
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           H2OJ0006
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           H2OJ0007
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP              H2OJ0008
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   H2OJ0009
      COMMON /TOLER/DELTA                                               H2OJ0010
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)      H2OJ0011
      COMMON /CONST/ PI,G,RHOD                                          H2OJ0012
      COMMON /STRTC/TC,T,C,T1,C1,CFM                                    H2OJ0013
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /ITABL/L(2)                                                H2OJ0015
      COMMON IFUEL,IPUMP,TYGER
      EQUIVALENCE (VJVO,PARM(1))                                        H2OJ0017
      DIMENSION PARM(3),ENGN(3,12),EHP(5),DEL(4),DLMIN(4),PMIN(5)       H2OJ0018
      DIMENSION VK(5)                                                   H2OJ0019
      EXTERNAL FCT                                                      H2OJ0020
      DATA IPRNT/6/                                                     H2OJ0021
      DATA ENGN/4HTF35,2*4H    ,4HTF40,2*4H    ,4HPRCT, 4HEUS ,4H1500,  H2OJ0022
     A 4HPROT,4HEUS ,4H1000,  4HTYNE,4H 1A ,4H    ,4HTYNE,4H 1C ,4H    ,H2OJ0023
     B 4HFT12,4HA   ,4H    ,4HLM15,4H00  ,4H    ,4HLM25,4H00  ,4H    ,  H2OJ0024
     C 4HFT4A,4H-2C ,4H    ,4HFT4A,4H-12 ,4H    ,4HFT4C,4H-2  ,4H    /  H2OJ0025
      DATA DLMIN/4*.01/                                                 H2OJ0026
      IFUEL=.TRUE.                                                      H2OJ0027
      IPUMP=.FALSE.                                                     H2OJ0028
      DISPL=DISP/2240.                                                  H2OJ0029
C     DETERMINE ENGINE TYPE                                             H2OJ0030
C     IENGN CONTAINS CODING OF GAS TURBINE MODEL                        H2OJ0031
```

```
C                                                                       H20J0032
C        IENGN     GAS TURBINE                                          H20J0033
C                                                                       H20J0034
C        1         TF35                                                 H20J0035
C        2         TF40                                                 H20J0036
C        3         PROTEUS 1500 RPM                                     H20J0037
C        4         PROTEUS 1000 RPM                                     H20J0038
C        5         TYNE 1A                                              H20J0039
C        6         TYNE 1C                                              H20J0040
C        7         FT12A                                                H20J0041
C        8         LM1500                                               H20J0042
C        9         LM2500                                               H20J0043
C        10        FT4A-20                                              H20J0044
C        11        FT4A-12                                              H20J0045
C        12        FT4C-2                                               H20J0046
C                                                                       H20J0047
C     DETERMINE WHICH POINTS ARE INPUT                                  H20J0048
C                                                                       H20J0049
      ISTRT=1                                                           H20J0050
      NUMB=2                                                            H20J0051
      IF(IEVAL.EQ.0) GO TO 3
      IF(IEVAL.LT.0) ISTRT=3
      IF(IEVAL.LT.0)NUMB=2+IABS(IEVAL)
    3 JNUM=2+IABS(IEVAL)
      DO 1 I=ISTRT,JNUM
      VK(I)=VO(I)*0.5921
    1 TDRAG(I)=POD(I)+STRTD(I)+SPRAY(I)+REST(I)                         H20J0054
C                                                                       H20J0055
C     IEVAL.LT.0 IMPLIES NO CRUISE OR TAKE-OFF POINTS SPECIFIED,        H20J0056
C     ABS(IEVAL) INDICATES HOW MANY POINTS FOR PERFORMANCE ESTIMATION   H20J0057
C     IEVAL.EQ.0 IMPLIES DESIGN AT CRUISE AND TAKE-OFF ONLY             H20J0058
C     IEVAL.GT.0 IMPLIES DESIGN AT CRUISE/TAKE-OFF AND ESTIMATE PERFORM.H20J0059
C     AT IEVAL POINTS                                                   H20J0060
C     IF ENTERED, CRUISE POINTS ARE IN FIRST POSITION IN ARRAY, TAKE-OFFH20J0061
C     POINTS IN SECOND AND PERFORMANCE ESTIMATION POINTS IN REMAINING   H20J0062
C     POSITIONS                                                         H20J0063
```

```
C     IEQPT NON-ZERO IMPLIES SPECIFIC TYPE EQUIPMENT TO BE INPUT BY USERH20J0064
C     IEQPT.EQ.1 IMPLIES NUMBER OF GAS TURBINES IS SPECIFIED BY USER
C     IEQPT.EQ.3 IMPLIES NUMBER OF GAS TURBINES AND NUMBER OF PUMPS
C     ARE SPECIFIED BY USER
C
C     TYGER.EQ..TRUE. IMPLIES GEAR TYPE, IGEAR, IS SPECIFIED BY USER
C     TYGER.EQ..FALSE. IMPLIES GEAR TYPE TO BE SELECTED BY PROGRAM
C        IGEAR           TYPE OF GEAR
C          1        SINGLE REDUCTION WITH IDLER
C          2        PLANETARY
C          3        DOUBLE REDUCTION, DOUBLE BRANCH
C
      IF(ISTRT.NE.1) GO TO 4                                            H20J0066
      WRITE(IPRNT,5)                                                    H20J0067
    5 FORMAT(1H1,10X,58H *** WATERJET PROPULSION SYSTEM DESIGN AND PERFOH20J0068
     ARMANCE ***,///)                                                   H20J0069
      WRITE(IPRNT,31)                                                   H20J0070
      WRITE(IPRNT,6)                                                    H20J0071
    6 FORMAT(12H OPERATIONAL,/)                                         H20J0072
      WRITE(IPRNT,7)                                                    H20J0073
    7 FORMAT(30X,6HCRUISE,15X,8HTAKE-OFF,/)                             H20J0074
      WRITE(IPRNT,8) (VK(N),N=1,2)                                      H20J0075
    8 FORMAT(16H VELOCITY, KNOTS,14X,F5.1,17X,F5.1)                     H20J0076
      WRITE(IPRNT,9) (TDRAG(N),N=1,2)                                   H20J0077
    9 FORMAT(16H TOTAL DRAG, LBS,13X,F7.0,15X,F7.0)                     H20J0078
      WRITE(IPRNT,10) (TRIM(N),N=1,2)                                   H20J0079
   10 FORMAT(25H ANGLE OF ATTACK, DEGREES,6X,F4.1,18X,F4.1,//)          H20J0080
      IF(IEVAL.EQ.0) GO TO 11                                           H20J0081
      WRITE(IPRNT,12)                                                   H20J0082
   12 FORMAT(/,48H PERFORMANCE EVALUATION AT THE FOLLOWING POINTS,/)    H20J0083
      GO TO 13                                                          H20J0084
    4 WRITE(IPRNT,14)                                                   H20J0085
   14 FORMAT(1H1,10X,47H *** WATERJET PROPULSION SYSTEM PERFORMANCE ***,H20J0086
     A ///)                                                             H20J0087
   13 IM=IABS(IEVAL)                                                    H20J0088
      WRITE(IPRNT,6)                                                    H20J0089
```

```
      DO 15 I=1,IM                                                      H20J0090
      J=I+2                                                             H20J0091
   15 WRITE(IPRNT,16) VK(J),TDRAG(J),TRIM(J)                            H20J0092
   16 FORMAT(16H VELOCITY, KNOTS,14X,F5.1,/,16H TOTAL DRAG,LBS,13X,F7.0,H20J0093
     A /,25H ANGLE OF ATTACK, DEGREES,6X,F4.1,//)                       H20J0094
      WRITE(IPRNT,31)                                                   H20J0095
   31 FORMAT(22H CRAFT CHARACTERISTICS,//)                              H20J0096
   11 WRITE(IPRNT,17)                                                   H20J0097
   17 FORMAT(14H CONFIGURATION,/)                                       H20J0098
      WRITE(IPRNT,18) BEAM,DISPL,RANGE,(ENGN(N,IENGN),N=1,3)            H20J0099
   18 FORMAT(28H AVERAGE BEAM, FEET........., F7.1,/,28H DISPLACEMENT, LH20J0100
     AONG TONS...., F7.0,/,28H ENDURANCE, NM..............,F7.0,/,28H GAH20J0101
     BS TURBINE PLANT..........,3X,3A4,//)                              H20J0102
      WRITE(IPRNT,19) HS,HE,HCL,XLS,XLPE                                H20J0103
   19 FORMAT(48H DEPTH OF SUBMERGENCE OF NACELLE................,F5.1,2XH20J0104
     A,4HFEET,/,48H HEIGHT OF PUMP CENTERLINE ABOVE MEAN WATER.....,F5.1H20J0105
     B,2X,4HFEET,/,48H HEIGHT OF PUMP CENTERLINE ABOVE KEEL..........., H20J0106
     CF5.1,2X,4HFEET,/,48H DISTANCE OF STRUT FROM TRANSOM...............H20J0107
     D..,F5.1,2X,4HFEET,/,48H DISTANCE OF PUMP EXIT FROM TRANSOM........H20J0108
     E.....,F5.1,2X,4HFEET,//)                                          H20J0109
      WRITE(IPRNT,20)                                                   H20J0110
   20 FORMAT(10X,17H WATER PROPERTIES,/,10X,45H (ASSUMES STANDARD(3.5% SH20J0111
     1ALINITY) SALT WATER),//)                                          H20J0112
C                                                                       H20J0113
C     TEMP IS THE TEMPERATURE OF THE WATER IN DEGREES FAHRENHEIT        H20J0114
C                                                                       H20J0115
   25 PV=.11413E-7*TEMP**4+.12435E-6*TEMP**3+.49859E-4*TEMP*TEMP+.29719EH20J0116
     A-2*TEMP+.032335                                                   H20J0117
      GNU=EXP(-.6201E-6*TEMP**3+.1749E-3*TEMP*TEMP-.02796*TEMP+1.414)*  H20J0118
     A 1.E-5                                                            H20J0119
      RHOW=(-.79965E-6*TEMP**4+.18714E-3*TEMP**3-.015982*TEMP*TEMP+.5817H20J0120
     A*TEMP+56.569)/G                                                   H20J0121
      HA=2117./(RHOW*G)                                                 H20J0122
      WRITE(IPRNT,21) TEMP,RHOW,GNU,PV                                  H20J0123
   21 FORMAT(32H TEMPERATURE, DEGREES FAHRENHEIT,5X,F4.0,/,             H20J0124
     A 28H DENSITY, LBF-SEC**2/FEET**4,9X,F6.3,/,                       H20J0125
```

```
   B 31H VISCOSITY, *10**5, FEET**2/SEC,6X,5PF6.3,/,                    H20J0126
   C 21H VAPOR PRESSURE, FEET,16X,0PF6.3,///)                           H20J0127
    WRITE(IPRNT,22) G                                                   H20J0128
 22 FORMAT(36H ACCELERATION OF GRAVITY, FT/SECS**2,6X,F7.3,///)         H20J0129
    IF(IEQPT.NE.0) GO TO 23                                             H20J0130
    IF(TYGER) GO TO 23
    WRITE(IPRNT,24)                                                     H20J0131
 24 FORMAT(68H NO EQUIPMENTS OR CONFIGURATIONS SPECIFIED. GENERATED ASH20J0132
   A PER PROGRAM,/,1H1)                                                 H20J0133
    GO TO 32                                                            H20J0134
 33 WRITE(IPRNT,34) (ENGN(I,IENGN),I=1,3)                               H20J0135
 34 FORMAT(16H MORE THAN FOUR ,3A4,30H REQUIRED. INVALID PRIME MOVER) H20J0136
    RETURN                                                              H20J0137
 23 WRITE(IPRNT,26)                                                     H20J0138
 26 FORMAT(1H1,' THE FOLLOWING EQUIPMENT, ETC. SPECIFIED.....')         H20J0139
    IF(TYGER) GO TO(101,102,103),IGEAR
    GO TO 104
101 WRITE(IPRNT,112)
112 FORMAT(//,51H SPECIFIED GEAR TYPE IS SINGLE REDUCTION WITH IDLER,/
   A/)
    GO TO 104
102 WRITE(IPRNT,113)
113 FORMAT(//,33H SPECIFIED GEAR TYPE IS PLANETARY,//)
    GO TO 104
103 WRITE(IPRNT,114)
114 FORMAT(//,55H SPECIFIED GEAR TYPE IS DOUBLE REDUCTION, DOUBLE BRAN
   ACH,//)
104 IF(IEQPT.EQ.0) GO TO 32
    IF(IEQPT.NE.1) GO TO 131
    WRITE(IPRNT,121) NGT
121 FORMAT(//,37H SPECIFIED NUMBER OF GAS TURBINES IS ,I2,//)
    GO TO 141
131 WRITE(IPRNT,122) NGT,NPUMP
122 FORMAT(//,37H SPECIFIED NUMBER OF GAS TURBINES IS ,I2,/,30H SPECIF
   AIED NUMBER OF PUMPS IS ,I2,//)
    GO TO 141
```

```
C     COMMENCE DESIGN/PERFORMANCE PREDICTION                            H20J0144
C                                                                       H20J0145
C                                                                       H20J0146
C     FIRST CHECK ON MINIMUM NUMBER OF GAS TURBINES REQUIRED, GIVEN THE H20J0147
C     TYPE AND EHP. THEN CYCLE THROUGH THE PUMP COMBINATIONS POSSIBLE.  H20J0148
C                                                                       H20J0149
   32 IF(ISTRT.NE.1) GO TO 38                                           H20J0150
      IN=1                                                              H20J0151
      MAX=3                                                             H20J0152
      ISAVE=4                                                           H20J0153
      XMIN=.25                                                          H20J0154
      DO 37 IK=ISTRT,NUMB                                               H20J0155
      IL=1                                                              H20J0156
      EHP(IK)=TDRAG(IK)*VO(IK)/550.                                     H20J0157
      DO 37 IJ=1,3                                                      H20J0158
      XJ=IJ+IJ/3                                                        H20J0159
      IM=IK/3                                                           H20J0160
      MK=IK-IM*(IK-2)                                                   H20J0161
      IF(1.5*EHP(IK).GT.XJ*PERF(MK,IENGN)) IL=IJ+1                      H20J0162
      IF(IK.GT.1) GO TO 39                                              H20J0163
      IF(EHP(IK)/XJ.LT.XMIN*PERF(1,IENGN)) ISAVE=XJ*.5                  H20J0164
      IF(ISAVE.LT.MAX) MAX=ISAVE                                        H20J0165
      IF(MAX.EQ.0) MAX=1                                                H20J0166
   39 IF(IL.GT.3) GO TO 33                                              H20J0167
   37 IF(IN.LT.IL) IN=IL                                                H20J0168
      TWGTS=1.E30                                                       H20J0169
      GO TO 144
  141 IN=1
      IF(ISTRT.NE.1) GO TC 38
      MAX=1
  144 DO 30 IK=IN,MAX
      IF(IEOPT.NE.0) GO TO 145
C                                                                       H20J0171
C     PUT MIN NUMBER GT'S REQUIRED IN HERE                              H20J0172
      NGT=IK+IK/3                                                       H20J0173
  145 KM=NGT/4+1
```

```
      K1=2*IK-NGT+1                                                     H20J0175
      IF(IEQPT.LE.1) GO TO 143
      K1=KM
  143 DO 28 I=KM,K1
      IF(IEQPT.GT.1) GO TO 142
      NPUMP=I+I/3                                                       H20J0181
  142 DELTA=.05
      DEL(1)=.5                                                         H20J0178
      DEL(2)=.2                                                         H20J0179
      DEL(3)=.3                                                         H20J0180
      VJVO=1.8                                                          H20J0182
      VIVO=.7                                                           H20J0183
      DIDM=.6                                                           H20J0184
      CALL PTTRN(PARM,WEIGT,3,FCT,DEL,DLMIN)                            H20J0185
      DELTA=0.0                                                         H20J0186
      WEIGT=FCT(PARM)/2240.                                             H20J0187
      IF(WEIGT.GT.TWGTS) GO TO 52                                       H20J0188
      DO 53 JK=1,3                                                      H20J0189
   53 PMIN(JK)=PARM(JK)                                                 H20J0190
      PMIN(4)=NGT                                                       H20J0191
      PMIN(5)=NPUMP                                                     H20J0192
   52 WRITE(IPRNT,50) WEIGT                                             H20J0193
   50 FORMAT(10X,21H*** SYSTEM WEIGHT IS ,F10.2,9H TONS ***)            H20J0194
      WRITE(IPRNT,51) NGT,NPUMP                                         H20J0195
   51 FORMAT(//,27H NUMBER OF GAS TURBINES IS ,I2,/,20H NUMBER OF PUMPS H20J0196
     AIS ,I2,//)                                                        H20J0197
      CALL OUTPUT                                                       H20J0198
   28 CONTINUE                                                          H20J0199
   30 CONTINUE                                                          H20J0200
      IF(IEVAL.EQ.0) RETURN                                             H20J0201
      IF(IEVAL.NE.0) ISTRT=3
      NUMB=2+IABS(IEVAL)
   38 DELTA=0.0
      IPUMP=.TRUE.
      WEIGT=FCT(PARM)/2240.                                             H20J0207
      WRITE(IPRNT,50) WEIGT                                             H20J0208
```

```
      WRITE(IPRNT,51) NGT,NPUMP                                         H20J0209
      CALL OUTPUT                                                       H20J0210
      RETURN                                                            H20J0213
      END                                                               H20J0214
```

```
      FUNCTION FCT(PARM)                                                FCT 0001
      LOGICAL IFUEL,IPUMP,TYGER
      REAL JANGL
      COMMON /NOZL/JANGL
      COMMON /WARN/CAV(5,6)
      COMMON /PINLP/ALPHA
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           FCT 0003
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)      FCT 0004
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   FCT 0005
      COMMON /FLBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           FCT 0006
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP              FCT 0007
      COMMON /NACLL/CRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN,AAX(5)
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   FCT 0009
      COMMON /CONST/PI,G,RHOD                                           FCT 0010
      COMMON /PUMN/QQ(5),D1S(5),D2S(5),XNS(5),SM(5,5),PLP(5),NSTG,SHI(5,
     A5),XIM
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),     FCT 0013
     1 TRIM(5)                                                          FCT 0014
      COMMON /CDRAG/CSTRT(5),CPOD(5),CSPRY(5)                           FCT 0015
      COMMON /TOLER/ DELTA                                              FCT 0016
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /ITABL/L(2)                                                FCT 0018
      COMMON IFUEL,IPUMP,TYGER
      DIMENSION PARM(4),APOD(5),ASTRT(5),ASPRY(5),C(5),DDRAG(5),DSPRY(5)FCT 0020
     A ,DSTRT(5),DPOD(5)                                                FCT 0021
      DATA C/1.,1.25,3*1./                                              FCT 0022
      IF(ISTRT.NE.1) GO TO 101
      IF(.NOT.IPUMP) XLP=5.                                             FCT 0023
      TSUM=1.E9                                                         FCT 0024
C                                                                       FCT 0025
C     POP BACK TO OPTIMIZATION IF BOUNDS EXCEEDED                       FCT 0026
C                                                                       FCT 0027
      IF(PARM(1).GT.5..AND.DELTA.GT.1.E-9) GO TO 8                      FCT 0028
      IF(PARM(1).LT.1.1) GO TO 8                                        FCT 0029
      IF(PARM(2).LT..5) GO TO 8                                         FCT 0030
```

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      IF(PARM(2).GT.1.5) GO TO 8                                       FCT 0031
      IF(PARM(3).GT..9) GO TO 8                                        FCT 0032
      IF(PARM(3).LE.0..AND.DELTA.GT.1.E-9) GO TO 8                     FCT 0033
      DRAT=PARM(3)                                                     FCT 0034
  101 DO 15 J=ISTRT,NUMB
      DSTRT(J)=STRTD(J)                                                FCT 0036
      DPOD(J)=POD(J)                                                   FCT 0037
      DSPRY(J)=SPRAY(J)                                                FCT 0038
   15 DDRAG(J)=TDRAG(J)                                                FCT 0039
      IF(ISTRT.NE.1) GO TO 102
      VJ(1)=VO(1)*PARM(1)                                              FCT 0040
      VI(1)=VO(1)*PARM(2)                                              FCT 0041
   10 ANGLE=ATAN(TDRAG(1)/DISP)                                        FCT 0042
      JANGL=ANGLE
      IF(TDRAG(1)/DISP.GT..2.AND.DELTA.GT.1.E-9) GO TO 8               FCT 0043
      IF(TDRAG(1)/DISP.LT..05.AND.DELTA.GT.1.E-9) GO TO 8              FCT 0044
      COEF=1.                                                          FCT 0045
      Q(1)=TDRAG(1)/(RHOW*(VJ(1)*COS(ANGLE)-VO(1)))                    FCT 0046
      AIN=Q(1)/VI(1)                                                   FCT 0047
      AJET=Q(1)/VJ(1)                                                  FCT 0048
      I=2                                                              FCT 0049
  102 IF(ISTRT.EQ.3) I=3
      IF(ISTRT.EQ.3) ANGLE=JANGL
      DO 5 J=I,NUMB                                                    FCT 0051
      SPD=.5*VO(J)/COS(ANGLE)                                          FCT 0052
      VJ(J)=SPD+SQRT(SPD*SPD+C(J)*TDRAG(J)/(RHOW*AJET*COS(ANGLE)))     FCT 0053
      Q(J)=AJET*VJ(J)                                                  FCT 0054
    5 VI(J)=Q(J)/AIN                                                   FCT 0055
      ICOMP=1                                                          FCT 0056
      CALL NACEL                                                       FCT 0057
      IF(WGTS(1,1).GT.DISP.AND.DELTA.GT.1.E-9) GO TO 8                 FCT 0058
      IF(DELTA.LT.1.E-5) PARM(3)=DRAT                                  FCT 0059
      ICOMP=2                                                          FCT 0060
      DEPTH=SQRT(AREA(1))                                              FCT 0061
      WIDTH=.5*DEPTH                                                   FCT 0062
      CALL ELBOW                                                       FCT 0063
```

```
      CGS(1,ICOMP)=HCL-HE-HS                                            FCT 0064
      CGS(2,ICOMP)=XLS                                                  FCT 0065
      IF(THATA(2).NE.90.) CGS(2,ICOMP)=CGS(2,ICOMP)+(HE-RO(1)*XK(1)+HS)/FCT 0066
     A TAN(THATA(2)*.0174533)                                           FCT 0067
      WGTS(1,ICOMP)=WGTS(1,ICOMP)*(RHOD-RHOW)/RHOD                      FCT 0068
      WGTS(2,ICOMP)=0.                                                  FCT 0069
   12 ICOMP=3                                                           FCT 0070
      CALL STRUT                                                        FCT 0071
      IF(WGTS(1,ICOMP).GT.DISP) GO TO 8                                 FCT 0072
      J=NUMB                                                            FCT 0073
      IF(ISTRT.EQ.1) J=2                                                FCT 0074
C                                                                       FCT 0075
C     SEE IF NEWLY COMPUTED DRAG DIFFERS SIGNIFICANTLY (I.E. GREATER    FCT 0076
C     THAN 5%) FROM PREVIOUS ESTIMATE. IF SO, RECOMPUTE ON BASIS OF NEW FCT 0077
C     DRAG. OTHERWISE CONTINUE.                                         FCT 0078
C                                                                       FCT 0079
      JDRAG=1                                                           FCT 0080
      DEV=.05                                                           FCT 0081
      IF(DELTA.LT.1.E-9) DEV=.01                                        FCT 0086
      DO 9 I=ISTRT,J                                                    FCT 0082
      APOD(I)=COEFF*(CPOD(I)-POD(I))                                    FCT 0083
      ASTRT(I)=CSTRT(I)-STRTD(I)                                        FCT 0084
      ASPRY(I)=CSPRY(I)-SPRAY(I)                                        FCT 0085
      IF(ABS(APOD(I)+ASTRT(I)+ASPRY(I)).GE.DEV*TDRAG(I)) JDRAG=2        FCT 0087
      SPRAY(I)=CSPRY(I)                                                 FCT 0088
      STRTD(I)=CSTRT(I)                                                 FCT 0089
      POD(I)=CPOD(I)                                                    FCT 0090
    9 TDRAG(I)=REST(I)+POD(I)+STRTD(I)+SPRAY(I)                         FCT 0091
      IF(JDRAG.EQ.2.AND.ISTRT.EQ.3) GO TO 102
      IF(JDRAG.EQ.2) GO TO 10                                           FCT 0092
      ICOMP=4                                                           FCT 0093
      CALL ELBOW                                                        FCT 0094
      CGS(1,ICOMP)=HCL                                                  FCT 0095
      CGS(2,ICOMP)=XLS                                                  FCT 0096
      CGS(3,ICOMP)=CGS(1,ICOMP)                                         FCT 0097
      CGS(4,ICOMP)=XLS                                                  FCT 0098
```

```
      ICOMP=5                                                           FCT 0099
      GO TO (1,2,3,3),NPUMP                                             FCT 0100
    1 CALL JUNCT                                                        FCT 0101
      GO TO 4                                                           FCT 0102
    2 CALL PIPE                                                         FCT 0103
      GO TO 4                                                           FCT 0104
    3 CALL DIVRG                                                        FCT 0105
    4 ICOMP=9                                                           FCT 0106
      DSIG=4.                                                           FCT 0107
      DO 13 KOUNT=ISTRT,NUMB                                            FCT 0108
      TOTAL=VO(KOUNT)**2/G*.5-DELH(KOUNT,6)-PV+HA                       FCT 0109
      SIGMA=TOTAL-(Q(KOUNT)/AREA(6))**2*.5/G                            FCT 0110
      IF(SIGMA.GT.0.) GO TO 13                                          FCT 0111
      CAV(KOUNT,5)=1.
      IF(ISTRT.EQ.3) GO TO 13
      IF(SIGMA.GT.DSIG) GO TO 13                                        FCT 0112
      COEFF=0.                                                          FCT 0113
      DSIG=SIGMA                                                        FCT 0114
      AREA(4)=1.05*Q(KOUNT)/SQRT(2.*G*TOTAL)                            FCT 0115
   13 CONTINUE                                                          FCT 0116
      IF(DSIG.NE.4.) GO TO 12                                           FCT 0117
   14 CONTINUE                                                          FCT 0118
      CALL NOZZL                                                        FCT 0119
      IF(WGTS(1,ICOMP).GT.DISP.AND.DELTA.GT.1.E-9) GO TO 8              FCT 0120
      ICOMP=8                                                           FCT 0121
      IF(ISTRT.NE.3) NSTG=0.
      CALL PUMP                                                         FCT 0122
      IF(ISTRT.EQ.3) GO TO 17
      IF(IPUMP) NNSTG=NSTG                                              FCT 0123
      IF(IPUMP) GO TO 12                                                FCT 0124
      IF(NNSTG.EQ.NSTG.OR .DELTA.GT.1.E-9) GO TO 17                     FCT 0125
      IPUMP=.TRUE.                                                      FCT 0126
      NNSTG=NSTG                                                        FCT 0127
      GO TO 12                                                          FCT 0128
   17 DO 11 J=ISTRT,NUMB                                                FCT 0129
   11 DELH(J,9)=DELH(J,7)+DELH(J,8)                                     FCT 0130
```

```
      ZSUM=0.                                                          FCT 0131
      XSUM=0.                                                          FCT 0132
      TSUM=0.                                                          FCT 0133
      WGTS(1,12)=PERF(5,IENGN)*FLOAT(NGT)                              FCT 0134
      DO 6 J=1,2                                                       FCT 0135
      SUM=0.                                                           FCT 0136
      SUMX=0.                                                          FCT 0137
      SUMZ=0.                                                          FCT 0138
      DO 7 I=1,12                                                      FCT 0139
      SUMZ=SUMZ+WGTS(J,I)*CGS(2*J-1,I)                                 FCT 0140
      SUMX=SUMX+WGTS(J,I)*CGS(2*J,I)                                   FCT 0141
    7 SUM=SUM+WGTS(J,I)                                                FCT 0142
      WGTS(J,14)=SUM                                                   FCT 0143
      CGS(2*J-1,13)=SUMZ/SUM                                           FCT 0144
      CGS(2*J,13)=SUMX/SUM                                             FCT 0145
      TSUM=TSUM+SUM                                                    FCT 0146
      XSUM=XSUM+SUMX                                                   FCT 0147
    6 ZSUM=ZSUM+SUMZ                                                   FCT 0148
      CGSX=XSUM/TSUM                                                   FCT 0149
      CGSZ=ZSUM/TSUM                                                   FCT 0150
      WGTS(2,13)=-RHOW*Q(1)*VJ(1)*SIN(ANGLE)                           FCT 0151
      WGTS(2,14)=WGTS(2,14)+WGTS(2,13)                                 FCT 0152
      TSUM=TSUM+WGTS(2,13)                                             FCT 0153
    8 FCT=TSUM                                                         FCT 0154
      IF(FCT.LT.DISP.OR.DELTA.LT.1.E-5) RETURN                         FCT 0155
      DO 16 I=ISTRT,NUMB                                               FCT 0156
      SPRAY(I)=DSPRY(I)                                                FCT 0157
      POD(I)=DPOD(I)                                                   FCT 0158
      STRTD(I)=DSTRT(I)                                                FCT 0159
   16 TDRAG(I)=DDRAG(I)                                                FCT 0160
      RETURN                                                           FCT 0161
      END                                                              FCT 0162
```

```
      SUBROUTINE ELBCW                                                  ELBOW000
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   ELBOW001
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP              ELBOW002
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           ELBOW003
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           ELBOW004
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   ELBOW005
      COMMON /CONST/PI,G,RHOD                                           ELBOW006
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /ITABL/L(2)                                                ELBOW008
C                                                                       ELBOW009
C     ELBOW PERFORMANCE AND DESIGN                                      ELBOW010
C                                                                       ELBOW011
C     REQUIRED INPUT                                                    ELBOW012
C        WIDTH - WIDTH OF DUCT AT ELBOW INLET                           ELBOW013
C        DEPTH - HEIGHT OF DUCT AT ELBOW INLET                          ELBOW014
C        XK    - RADIUS RATIO, RATIO OF THE RADIUS OF THE CENTERLINE OF ELBOW015
C                BEND TO THE INTERNAL RADIUS OF THE DUCT                ELBOW016
C        Q     - FLOW RATE, IN CUBIC FEET PER SECOND                    ELBOW017
C        AREA  - CROSS SECTIONAL AREA OF DUCT AT THE ELBOW, PRESUMED    ELBOW018
C                SAME AT THE INLET AND THE OUTLET                       ELBOW019
C        THATA - ANGLE OF BEND, FROM HORIZONTAL TO OUTSIDE EDGE         ELBOW020
C        GNU   - VISCOSITY OF STANDARD (35 PER CENT SALINITY) SALT WATERELBOW021
C        PI    - 3.14159265                                             ELBOW022
C        ICOMP - INDEX INDICATING WHICH COMPONENT IS BEING LOOKED AT    ELBOW023
C        ISTRT - INDEX NOTING WHICH MODE OF OPERATION FOR THE HYDROFOIL ELBOW024
C        NUMB  - INDEX NOTING HOW MANY MODES TO BE CONSIDERED DURING    ELBOW025
C                THIS PASS                                              ELBOW026
C                                                                       ELBOW027
      DIMENSION SHAPE(3,4),THETA(11),XLOSS(11),ROA(10)                  ELBOW028
      DATA SHAPE/4H ELL,4HIPSE,4H    ,4H CIR,4HCLE ,4H    ,4H REC,      ELBOW029
     A 4HTANG,4HLE  ,4H SQU,4HARE ,4H    /                              ELBOW030
      DATA THETA/0.,10.,20.,30.,40.,50.,60.,70.,80.,90.,95./            ELBOW031
      DATA XLOSS/0.,0.029,0.059,0.08,0.107,0.133,0.156,0.176,0.19,0.198,ELBOW032
     A0.198/                                                            ELBOW033
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)         ELBOW034
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```
      CORR(RE)=1.00057-.16892*ALOG(RE*1.E-5)+.0145385*ALOG(RE*1.E-5)**2 ELBOW035
     A -.16948E-2*ALOG(RE*1.E-5)**3                                     ELBOW036
      REMAX=4.E+5                                                       ELBOW037
      KOUNT=ISTRT                                                       ELBOW038
      IELB=ICOMP-ICOMP/2                                                ELBOW039
      AREA(ICOMP)=AREA(ICOMP-1)                                         ELBOW040
      AREA1=.5*AREA(ICOMP)                                              ELBOW041
      IF(IELB.EQ.4) AREA1=.5*AREA1                                      ELBOW042
C                                                                       ELBOW043
C     DETERMINE SHAPE                                                   ELBOW044
C                                                                       ELBOW045
      IJ=0                                                              ELBOW046
      IK=1                                                              ELBOW047
      IF(WIDTH.EQ.DEPTH) IJ=1                                           ELBOW048
      IF(ABS(WIDTH*DEPTH-AREA1).LT..05*AREA1) IK=3                      ELBOW049
      ITYPE=IJ+IK                                                       ELBOW050
C                                                                       ELBOW051
C        ITYPE      SHAPE                                               ELBOW052
C                                                                       ELBOW053
C          1        ELLIPSE                                             ELBOW054
C          2        CIRCLE                                              ELBOW055
C          3        RECTANGLE                                           ELBOW056
C          4        SQUARE                                              ELBOW057
C                                                                       ELBOW058
      FACTR=(.00229+.041452*XK(IELB)**(-1.96))*XK(IELB)**.84            ELBOW059
C                                                                       ELBOW060
C     DETERMINE EQUIVALENT RADII                                        ELBOW061
C                                                                       ELBOW062
      RO(IELB)=.5*DEPTH                                                 ELBOW063
      IF(ITYPE.EQ.1) RO(IELB)=WIDTH*DEPTH*SQRT(2./(WIDTH**2+DEPTH**2))  ELBOW064
C                                                                       ELBOW065
C     TRANSFER SHAPE TO CALLING PROGRAM                                 ELBOW066
C                                                                       ELBOW067
      DO 1 N=1,3                                                        ELBOW068
    1 TYPE(N,IELB)=SHAPE(N,ITYPE)                                       ELBOW069
C                                                                       ELBOW070
```

```
C     FIND BEND RADII                                                   ELBOW071
C                                                                       ELBOW072
      RIN=RO(IELB)*(XK(IELB)-1.)                                        ELBOW073
      ROUT=RIN+2.*RO(IELB)                                              ELBOW074
C                                                                       ELBOW075
C     IF XK=R/RO IS LE. 1. DO NOT USE SPLITTERS METHOD....              ELBOW076
C     USE THIN TURNING VANES CALCULATION                                ELBOW077
C                                                                       ELBOW078
      IF(XK(IELB).LE.1.) GO TO 100                                      ELBOW079
C                                                                       ELBOW080
C     DETERMINE NUMBER OF VANES REQUIRED FOR MINIMUM LOSS               ELBOW081
C     RATIO IS THE OPTIMUM RATIO OF THE INBOARD AND OUTBOARD RADII FOR  ELBOW082
C     MINIMUM LOSS IN THE BEND                                          ELBOW083
C                                                                       ELBOW084
      RATIO=4.3                                                         ELBOW085
      XN=ALOG((XK(IELB)-1.)/(XK(IELB)+1.))/ALOG((RATIO-1.)/(RATIO+1.))  ELBOW086
      N=XN+.5                                                           ELBOW087
      IF(N.EQ.0) N=1                                                    ELBOW088
      N1=N-1                                                            ELBOW089
      IF(N1.LE.0) N1=1                                                  ELBOW090
C                                                                       ELBOW091
C     FIND THE RATIO OF THE INSIDE RADIUS TO OUTSIDE RADIUS OF ANY OF THELBOW092
C     SUBDIVIDED ELBOWS                                                 ELBOW093
C                                                                       ELBOW094
      RATEO=(RIN/ROUT)**(1./FLOAT(N))                                   ELBOW095
C                                                                       ELBOW096
C     N = NUMBER OF SUBDIVIDED ELBOWS                                   ELBOW097
C     N1 = NUMBER OF SPLITTERS                                          ELBOW098
C                                                                       ELBOW099
C     COMPUTE HEAD LOSSES FOR EACH SUBDIVIDED ELBOW, STARTING FROM INSIDELBOW100
C     NOTE THE MAXIMUM REYNOLDS NUMBER THE EQUATION IS GOOD FOR, AND    ELBOW101
C     CORRECT FOR THE ACTUAL REYNOLDS NUMBER IF ABOVE THE MAXIMUM       ELBOW102
C     N.B. THE REYNOLDS NUMBER IS CALCULATED FROM THE SUBDIVIDED ELBOW, ELBOW103
C     NOT THE ORIGINAL ELBOW                                            ELBOW104
C                                                                       ELBOW105
    6 SUM=0.                                                            ELBOW106
```

```
      RIA=RIN                                                           ELBOW107
      V=Q(KOUNT)/AREA(ICOMP)                                            ELBOW108
      DO 3 I=1,N                                                        ELBOW109
      ROA(I)=RIA/RATEO                                                  ELBOW110
      HGT=ROA(I)-RIA                                                    ELBOW111
      AA=PI*HGT*HGT*.25                                                 ELBOW112
      IF(ITYPE.EQ.3.OR.ITYPE.EQ.4) AA=WIDTH*HGT                         ELBOW113
      RAD=HGT*PI*.25                                                    ELBOW114
      IF(ITYPE.EQ.3.OR.ITYPE.EQ.4) RAD=.5*(HGT+WIDTH)                   ELBOW115
      RE=AA*V/(RAD*GNU)                                                 ELBOW116
      XCORR=1.                                                          ELBOW117
      IF(RE.LT.REMAX) GO TO 7                                           ELBOW118
      XCORR=CORR(RE)/CORR(REMAX)                                        ELBOW119
      RE=REMAX                                                          ELBOW120
    7 XKT=XCORR*FACTR*THATA(IELB)*RE**(-.17)                            ELBOW121
      RIA=ROA(I)                                                        ELBOW122
    3 SUM=SUM+XKT*AA                                                    ELBOW123
      HEAD=SUM/AREA1+.5*V*V/G                                           ELBOW124
      GO TO 5                                                           ELBOW125
C                                                                       ELBOW126
C     THIN,CIRCULAR ARC TURNING VANE CALCULATIONS                       ELBOW127
C                                                                       ELBOW128
  100 XCORR=1.                                                          ELBOW129
      DIAM=2.*RO(IELB)                                                  ELBOW130
      IF(ITYPE.EQ.3.OR.ITYPE.EQ.4) DIAM=2.*WIDTH*DEPTH/(WIDTH**2+DEPTH**ELBOW131
     A 2)                                                               ELBOW132
      RE=DIAM*V/GNU                                                     ELBOW133
      IF(RE.GT.1.E+5) XCORR=CORR(RE)/CORR(1.E+5)                        ELBOW134
      XKT=TABLE(THETA,XLOSS,THATA(IELB),L)                              ELBOW135
      HEAD=(FRICT(RE)*RO(IELB)*XK(IELB)*THATA(IELB)*.0174533/DIAM+XKT)  ELBOW136
     A *.5*V*V/G*XCORR                                                  ELBOW137
    5 DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+HEAD                        ELBOW138
      IF(IELB.EQ.2) DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP)+RO(2)*XK(2)     ELBOW139
      IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 4                           ELBOW140
      KOUNT=KOUNT+1                                                     ELBOW141
      IF(XK(IELB).GT.1.) GO TO 6                                        ELBOW142
```

```
      V=Q(KOUNT)/AREA(ICOMP)                                            ELBOW143
      GO TO 100                                                         ELBOW144
C                                                                       ELBOW145
C     ELBOW STRUCTURE WEIGHT CALCULATIONS                               ELBOW146
C                                                                       ELBOW147
    4 VOLV=0.                                                           ELBOW148
      IF(XK(IELB).LE.1.) GO TO 9                                        ELBOW149
      DO 8 I=1,N1                                                       ELBOW150
    8 VOLV=VOLV+8.7267E-4*THATA(IELB)*ROA(I)*RIN*WIDTH                  ELBOW151
    9 VOL=VOLV+THATA(IELB)*RO(IELB)*XK(IELB)*AREA(ICOMP)/(134.56*RHOD)  ELBOW152
      WGTS(1,ICOMP)=VOL*RHOD*G                                          ELBOW153
      WGTS(2,ICOMP)=AREA(ICOMP)*RHOW*G*THATA(IELB)*RO(IELB)*XK(IELB)*   ELBOW154
     A .0174533                                                         ELBOW155
      RETURN                                                            ELBOW156
      END                                                               ELBOW157
```

```
      FUNCTION CFS(R)                                                   CFS  000
C                                                                       CFS  001
C     SCHOENHERR SKIN FRICTION COEFFICIENT                              CFS  002
C                                                                       CFS  003
      CFS=0.004                                                         CFS  004
    1 DCFS=(0.242/ALOG10(R*CFS))**2-CFS                                 CFS  005
      CFS=CFS+DCFS                                                      CFS  006
      IF(DCFS.GT.1.E-6) GO TO 1                                         CFS  007
      RETURN                                                            CFS  008
      END                                                               CFS  009
```

```
      FUNCTION TABLE(XTAB,YTAB,XIN,L)
      DIMENSION XTAB(2),YTAB(2),X(5),Y(5),A(5),B(5),L(2)
C
C     L(1)     - NUMBER OF PAIRS OF DATA POINTS ENTERED
C     L(2)     - DEGREE OF FIT, MAXIMUM IS FOUR
C     XTAB     - DATA ARRAY OF X VALUES
C     YTAB     - DATA ARRAY OF Y VALUES
C     XIN      - INDEPENDENT VARIABLE
C     TABLE    - DEPENDENT VARIABLE CORRESPONDING TO XIN
C
      NPTS=L(1)
      K=L(2)+1
      IF(K.GT.NPTS) K=NPTS
C
C     BRANCH TO TEN IF X IS INCREASING
C     BRANCH TO 160 IF X IS DECREASING
C     IF XTAB(1).EQ.XTAB(2) ABORT RUN
C
      IF(XTAB(1)-XTAB(2)) 10,290,160
   10 IF(XTAB(1)-XIN) 20,140,200
   20 DO 120 IX=2,NPTS
C
C     FIND XTAB VALUES BRACKETING XIN
C
      IF(XTAB(IX).LE.XTAB(IX-1)) GO TO 290
      IF(XTAB(IX)-XIN) 120,150,40
  120 CONTINUE
      GO TO 130
   40 CONTINUE
C
C     IF XIN LIES BETWEEN EITHER END POINT OF THE XTAB ARRAY AND ITS
C     ADJACENT POINT, THE INTERPOLATION IS LIMITED TO A SECOND DEGREE
C     FIT
      IF(IX.GT.2) GO TO 60
      IF(K.GT.3) K=3
   60 IF(IX.LT.NPTS) GO TO 80
```

```
      IF(K.GT.3) K=3                                                    TABLE036
   30 NDX=IX-K/2                                                        TABLE037
      IF(IX.LT.NPTS) GO TO 100                                          TABLE038
      NDX=NPTS-K+1                                                      TABLE039
  100 DO 110 IL=1,K                                                     TABLE040
C                                                                       TABLE041
C     XTAB  AND YTAB VALUES FOR THE XTAB VALUES BRACKETING XIN ARE      TABLE042
C     TRANSFERRED TO THE LAGRANGIAN EQUATION                            TABLE043
C                                                                       TABLE044
      X(IL)=XTAB(NDX)                                                   TABLE045
      Y(IL)=YTAB(NDX)                                                   TABLE046
      NDX=NDX+1                                                         TABLE047
  110 CONTINUE                                                          TABLE048
      GO TO 210                                                         TABLE049
  130 CONTINUE                                                          TABLE050
C                                                                       TABLE051
C     TO GET PAST STATEMENT NUMBER 120, XIN IS LARGER THAN THE LARGEST  TABLE052
C     VALUE OF X IN XTAB. EXTRAPOLATION IS NECESSARY TO FIND TABLE AT   TABLE053
C     XIN                                                               TABLE054
      TABLE=((YTAB(NPTS)-YTAB(NPTS-1))/(XTAB(NPTS)-XTAB(NPTS-1)))*      TABLE055
     A (XIN-XTAB(NPTS))+YTAB(NPTS)                                      TABLE056
      RETURN                                                            TABLE057
  140 IX=1                                                              TABLE058
  150 TABLE=YTAB(IX)                                                    TABLE059
      RETURN                                                            TABLE060
  160 IF(XIN-XTAB(1)) 170,140,200                                       TABLE061
  170 DO 190 IX=2,NPTS                                                  TABLE062
C                                                                       TABLE063
C     XTAB IS SEARCHED TO FIND THE VALUE CLOSEST TO XIN                 TABLE064
C                                                                       TABLE065
      IF(XTAB(IX).GE.XTAB(IX-1)) GO TO 290                              TABLE066
      IF(XIN-XTAB(IX)) 190,150,40                                       TABLE067
  190 CONTINUE                                                          TABLE068
      GO TO 130                                                         TABLE069
C                                                                       TABLE070
C     TO GO TO STATEMENT NUMBER 130 INDICATES XIN IS SMALLER THAN THE   TABLE071
```

```
C      SMALLEST VALUE OF X IN XTAB AND EXTRAPOLATION IS NECESSARY TO FINDTABLE072
C      TABLE FOR XIN                                                     TABLE073
  200 TABLE=((YTAB(2)-YTAB(1))/(XTAB(2)-XTAB(1)))*(XIN-XTAB(1))+YTAB(1) TABLE074
      RETURN                                                             TABLE075
  210 DO 220 LL=1,K                                                      TABLE076
      A(LL)=1.                                                           TABLE077
  220 B(LL)=1.                                                           TABLE078
      P=0.                                                               TABLE079
C                                                                        TABLE080
C      PERFORM LAGRANGIAN INTERPOLATION                                  TABLE081
C                                                                        TABLE082
      DO 280 N=1,K                                                       TABLE083
      DO 270 J=1,K                                                       TABLE084
      AA=XIN-X(J)                                                        TABLE085
      IF(J.EQ.N) GO TO 240                                               TABLE086
      A(N)=A(N)*AA                                                       TABLE087
  240 BB=X(N)-X(J)                                                       TABLE088
      IF(BB.EQ.0.) GO TO 270                                             TABLE089
      B(N)=B(N)*BB                                                       TABLE090
  270 CONTINUE                                                           TABLE091
      C=A(N)/B(N)*Y(N)                                                   TABLE092
  280 P=P+C                                                              TABLE093
      TABLE=P                                                            TABLE094
      RETURN                                                             TABLE095
C                                                                        TABLE096
C      EQUAL CONSECUTIVE OR NON-MONOTONIC VALUES OF X ENCOUNTERED IN XTABTABLE097
C                                                                        TABLE098
  290 TABLE=1.E30                                                        TABLE099
      RETURN                                                             TABLE100
      END                                                                TABLE101
```

```
      SUBROUTINE STRUT                                                  STRUT000
C     STRUT DIFFUSER                                                    STRUT001
C                                                                       STRUT002
C     REQUIRED INPUTS                                                   STRUT003
C        HE     - ELEVATION OF PUMP CENTERLINE ABOVE MEAN WATER         STRUT004
C        HS     - DEPTH OF SUBMERGENCE                                  STRUT005
C        RO(1) - HALF THE HEIGHT OF THE INLET TO THE DIFFUSER           STRUT006
C        RO(2) - HALF THE HEIGHT OF THE INLET TO THE HULL ELBOW         STRUT007
C        XK1    - RADIUS RATIO OF THE STRUT ELBOW                       STRUT008
C        XK2    - RADIUS RATIO OF THE HULL ELBOW                        STRUT009
C        ITYPE - 1 OR 3                                                 STRUT010
C             ONE - ELLIPSE                                             STRUT011
C             THREE - RECTANGLE                                         STRUT012
C        Q      - FLOW RATE IN CUBIC FEET PER SECOND                    STRUT013
C        PI     - 3.14159265                                            STRUT014
C        AREA   - AREA OF DUCT INLET                                    STRUT015
C                                                                       STRUT016
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED                     STRUT017
C        TABLE - ONE DIMENSIONAL TABLE LOOK UP FUNCTION SUBPROGRAM      STRUT018
C                                                                       STRUT019
      LOGICAL IFUEL,IPUMP                                               STRUT020
      COMMON /WARN/CAV(5,6)
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   STRUT021
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           STRUT022
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           STRUT023
      COMMON /STRTC/TC,T,C,T1,C1,CFM                                    STRUT024
      COMMON /CONST/PI,G,RHOD                                           STRUT025
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),     STRUT026
     1 TRIM(5)                                                          STRUT027
      COMMON /CDRAG/CSTRT(5),CPOD(5),CSPRY(5)                           STRUT028
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP               STRUT029
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   STRUT030
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /ITABL/L(2)                                                STRUT032
      COMMON IFUEL,IPUMP                                                STRUT033
```

```
      DIMENSION THET2(22),EXPAN(22)                                    STRUT034
      DATA THET2/0.,2.,4.,6.,8.,10.,12.,15.,17.5,20.,25.,27.,30.,32.,  STRUT035
     1 34.,39.,45.,50.,60.,70.,80.,90./                                STRUT036
      DATA EXPAN/0.,.005,.015,.03,.05,.09,.17,.3,.4,.5,.7,.8,.91,0.97, STRUT037
     A 1.0,1.03,1.04,1.04,1.037,1.035,1.033,1.03/                      STRUT038
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)        STRUT039
      IF(ISTRT.EQ.3) GO TO 10
C                                                                      STRUT040
C     FIND EFFECTIVE LENGTH FOR EITHER GENERALIZED RECTANGLE OR ELLIPSE STRUT041
      WGTS(1,ICOMP)=1.E9
      AREA(ICOMP)=2.*AREA(ICOMP-1)                                     STRUT043
      IF(.NOT.IPUMP) GO TO 5                                           STRUT044
      AREA(ICOMP)=AREA(8)                                              STRUT045
      IF(AREA(8).LT.AREA(7).AND.AREA(4).GT.AREA(7)) AREA(ICOMP)=AREA(4) STRUT046
    5 IF(AREA(ICOMP).LT.AREA(ICOMP-1)) AREA(ICOMP)=AREA(ICOMP-1)       STRUT047
      ARATO=AREA(ICOMP)/AREA(ICOMP-1)                                  STRUT048
C                                                                      STRUT049
C     SIZE STRUT EXTERNAL DIMENSIONS                                   STRUT050
C                                                                      STRUT051
      VL=1.137*VO(1)                                                   STRUT052
      SIGMA=(HA*G-PV*G)/(.5*VL*VL)                                     STRUT053
      TC=(SQRT(1.+SIGMA)-1.)/1.15                                      STRUT054
      IF(TC.LT..12) TC=.12                                             STRUT055
      C=SQRT(AREA(ICOMP)/TC)                                           STRUT056
      T=TC*C                                                           STRUT057
C                                                                      STRUT058
C     T AND C ARE THE THICKNESS AND CHORD AT THE STRUT EXIT            STRUT059
C                                                                      STRUT060
      C1=SQRT(AREA(ICOMP-1)/TC)                                        STRUT061
      T1=TC*C1                                                         STRUT062
C                                                                      STRUT063
C     C1 AND T1 ARE THE CHORD AND THICKNESS AT THE STRUT INLET         STRUT064
C                                                                      STRUT065
      GO TO 12
C     IF ISTRT=3, CHECK FOR CAVITATION
   10 DO 11 I=ISTRT,NUMB
```

```
      VL=1.137*VO(I)
      SIGMA=(HA*G-PV*G)/(.5*VL*VL)
      SIGMI=(1.15*TC+1.)**2-1.
      IF(SIGMA.LT.SIGMI) CAV(I,4)=1.
      ARATO=AREA(ICOMP)/AREA(ICOMP-1)
   11 CONTINUE
   12 CM=.5*(C+C1)
C                                                                       STRUT067
C     FIND EQUIVALENT DIAMETERS                                         STRUT068
C                                                                       STRUT069
      IF(ITYPE/2.EQ.0) GO TO 1                                          STRUT070
      DEIN=WIDTH*DEPTH/(WIDTH+DEPTH)                                    STRUT071
      WIDTH=SQRT(AREA(ICOMP))*.5                                        STRUT072
      WIDE=2.*WIDTH                                                     STRUT073
      DEOUT=WIDE*WIDTH/(WIDE+WIDTH)                                     STRUT074
      RO(2)=.5*WIDTH                                                    STRUT075
      GO TO 2                                                           STRUT076
    1 DEIN=WIDTH*DEPTH*SQRT(2./(WIDTH*WIDTH+DEPTH*DEPTH))               STRUT077
      WIDTH=SQRT(AREA(ICOMP)/PI)                                        STRUT078
      WIDE=2.*WIDTH                                                     STRUT079
      DEOUT=WIDTH*WIDE*SQRT(2./(WIDE*WIDE+WIDTH*WIDTH))                 STRUT080
      RO(2)=.5*DEOUT                                                    STRUT081
    2 DEAVE=DEIN+DEOUT                                                  STRUT082
      STRT=HE+HS-RO(1)*XK(1)-RO(2)*XK(2)                                STRUT083
      IF(STRT.LE.0.) RETURN                                             STRUT084
      XLONG=STRT/SIN(THATA(1)*.0174533)                                 STRUT085
C                                                                       STRUT086
C     FIND EQUIVALENT ANGLE OF DIFFUSER, TWO THETA                      STRUT087
C                                                                       STRUT088
      STAN=(WIDE-DEPTH)*.5/XLONG                                        STRUT089
      THETA=2.*ATAN(STAN)*57.29578                                      STRUT090
C                                                                       STRUT091
C     FIND EXPANSION COEFFICIENT                                        STRUT092
C                                                                       STRUT093
      ECOEF=TABLE(THET2,EXPAN,THETA,L)                                  STRUT094
C                                                                       STRUT095
```

```
C     FORM THE EXPANSION LOSS COEFFICIENT                                STRUT096
C                                                                        STRUT097
      FORML=ECOEF*(1.-1./ARATO)**2                                       STRUT098
C                                                                        STRUT099
C     DETERMINE INLET AND OUTLET VELOCITIES                              STRUT100
C                                                                        STRUT101
      DEPTH=WIDTH                                                        STRUT102
      WIDTH=WIDE                                                         STRUT103
      KOUNT=ISTRT                                                        STRUT104
    3 VELIN=Q(KOUNT)/AREA(ICOMP-1)                                       STRUT105
      VLOUT=VELIN/ARATO                                                  STRUT106
C                                                                        STRUT107
C     DETERMINE STRUT DRAG FROM HOERNER                                  STRUT108
C     DETERMINE SPRAY DRAG FROM SHERMAN AND LINCOLN                      STRUT109
C                                                                        STRUT110
      RES=CM*VO(KOUNT)/GNU                                               STRUT111
      CDS=2.*CFS(RES)*(1.+2.*TC+60.*TC**4)                               STRUT112
      CFM=HS/(HS+HE-PO(2)*XK(2))*(C-C1)+C1                               STRUT113
      CSTRT(KOUNT)=CDS*RHOW*VO(KOUNT)**2*HS/SIN(THATA(1)*.0174533)*.5    STRUT114
     A *(CFM+C1)                                                         STRUT115
      CDSP=.03*TC                                                        STRUT116
      CSPRY(KOUNT)=CSTRT(KOUNT)*(CDSP/CDS)                               STRUT117
C                                                                        STRUT118
C     CALCULATE THE STRAIGHT PIPE FRICTION COEFFICIENT                   STRUT119
C                                                                        STRUT120
      RE=VELIN*DEIN/GNU                                                  STRUT121
      PIPEL=FRICT(RE)*XLONG/DEIN                                         STRUT122
C                                                                        STRUT123
C     LOSS COEFFICIENT WHICH IS PROPORTIONAL TO VELOCITY HEAD AT INLET   STRUT124
C                                                                        STRUT125
      TOTAL=FORML+PIPEL                                                  STRUT126
C                                                                        STRUT127
C     HEAD LOSS DUE TO DIFFUSER                                          STRUT128
C                                                                        STRUT129
      HEADL=.5*TOTAL*VELIN*VELIN/G                                       STRUT130
C                                                                        STRUT131
```

```
C      TOTAL HEAD LOSS DUE TO DIFFUSER AND ELEVATION
C
       DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+HEADL+HE-RO(2)*XK(2)
       IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 4
       KOUNT=KOUNT+1
       GO TO 3
C
C      CENTER OF GRAVITY CALCULATIONS
C
     4 HGT=XLONG-HS+RO(1)*XK(1)
       CGWS=HGT*(3.*ARATO+2.*SQRT(ARATO)+1.)*.25/(ARATO+SQRT(ARATO)+1.)
       CGS(3,ICOMP)=-CGWS
       CGS(4,ICOMP)=XLS+CGWS*COTAN(THATA(1)*.0174533)
       CGS(1,ICOMP)=CGS(3,ICOMP)
       CGS(2,ICOMP)=CGS(4,ICOMP)
C
C      WEIGHT CALCULATIONS
C
       WGTS(1,ICOMP)=.250*(T+T1)*CM*XLONG*RHOW*G
       WGTS(2,ICOMP)=HGT/3.*AREA(ICOMP)*(ARATO+1.+SQRT(ARATO))*RHOW*G
       RETURN
       END
```

```
      SUBROUTINE JUNCT                                                  JUNCT000
      COMMON /PINLP/ALPHA
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   JUNCT001
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP               JUNCT002
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           JUNCT003
      COMMON /CONST/PI,G,RHOD                                           JUNCT004
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           JUNCT005
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   JUNCT006
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /ITABL/L(2)                                                JUNCT008
      DIMENSION BETA(19),ALAMD(19)                                      JUNCT009
      DATA ALAMD/.975,.97,.967,.963,.96,.957,.953,.95,.948,.945,.94,.93,JUNCT010
     A 0.92,0.9,0.85,0.81,0.75,0.69,0.61/                               JUNCT011
      DATA BETA/0.,5.,10.,15.,20.,25.,30.,35.,40.,45.,50.,55.,60.,65.,70JUNCT012
     A.,75.,80.,85.,90./                                                JUNCT013
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)         JUNCT015
      AREA(ICOMP)=AREA(ICOMP-1)                                         JUNCT016
C                                                                       JUNCT017
C     ALPHA IS ANGLE THAT ONE BRANCH MAKES WITH END PIPE IN JUNCTION    JUNCT018
      KOUNT=ISTRT                                                       JUNCT019
C                                                                       JUNCT020
C     MIXING LOSS COEFFICIENT OF JUNCTION                               JUNCT021
C                                                                       JUNCT022
      XLAMD=TABLE(BETA,ALAMD,ALPHA,L)                                   JUNCT023
      AMIXL=1.+XLAMD-2.*COS(.024434*ALPHA-.00583*(ALPHA*.0174533)**2)   JUNCT024
      IF(AMIXL.LT.0.) AMIXL=0.                                          JUNCT025
C                                                                       JUNCT026
      XPUMP=NGT+1                                                       JUNCT027
C                                                                       JUNCT028
C     ASSUMES NO LOSS DUE TO CHANGE OF SHAPE TO CIRCULAR                JUNCT029
C                                                                       JUNCT030
      DIAM=1.414*SQRT(AREA(ICOMP)/PI)                                   JUNCT031
      RO(3)=.5*DIAM                                                     JUNCT032
      AJCT=XLS-RO(3)*XK(3)-XLP-XLPE                                     JUNCT033
      IF(AJCT.LT.0.) AJCT=0.                                            JUNCT034
```

```
      FLONG=BEAM/XPUMP-RO(3)*(1.+XK(3))-RO(2)*XK(2)+RO(2)                 JUNCT035
      DEPTH=DIAM                                                          JUNCT036
      WIDTH=DEPTH                                                         JUNCT037
    2 ICOMP=5                                                             JUNCT038
C                                                                         JUNCT039
C     FIND HEAD LOSS FOR ATHWARTSHIPS LENGTH                              JUNCT040
C                                                                         JUNCT041
      V=Q(KOUNT)/AREA(ICOMP)                                              JUNCT042
      RE=V*DIAM/GNU                                                       JUNCT043
      FRCTL=FRICT(RE)*FLONG/DIAM                                          JUNCT044
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+FRCTL*.5*V*V/G                JUNCT045
      ICOMP=6                                                             JUNCT046
C                                                                         JUNCT047
C     FIND HEAD LOSS IN PUMP ELBCW                                        JUNCT048
C                                                                         JUNCT049
      CALL ELBOW                                                          JUNCT050
      RE=RE*1.414                                                         JUNCT051
C                                                                         JUNCT052
C     FRICTION LOSS COEFFICIENT IN JUNCTION                               JUNCT053
      FRCTJ=.3535*FRICT(RE)*AJCT/DIAM+FRCTL*AJCT/FLCNG*.5                 JUNCT054
C                                                                         JUNCT055
C     TOTAL JUNCTION LCSS CCEFFICIENT                                     JUNCT056
C                                                                         JUNCT057
      AJCTL=AMIXL+FRCTJ                                                   JUNCT058
C                                                                         JUNCT059
C     HEAD LOSS OF JUNCTION                                               JUNCT060
C                                                                         JUNCT061
      ICOMP=7                                                             JUNCT062
      DELH(KOUNT,ICOMP)=DELH(KCUNT,ICOMP-1)+AJCTL*.5*V*V/G                JUNCT063
      IF(KOUNT.EQ.2.OR.KCUNT.EQ.NUMB) GO TO 1                             JUNCT064
      KOUNT=KOUNT+1                                                       JUNCT065
      GO TO 2                                                             JUNCT066
    1 AREA(ICOMP)=AREA(ICOMP-1)                                           JUNCT067
C                                                                         JUNCT068
C     CENTER OF GRAVITY AND WEIGHT CALCULATICNS CF COMPONENTS OF PUMP     JUNCT069
C     INLET PIPING.                                                       JUNCT070
```

```
C                                                                       JUNCT071
      CGS(1,6)=HCL                                                      JUNCT072
      CGS(2,6)=XLS                                                      JUNCT073
      CGS(3,6)=HCL                                                      JUNCT074
      CGS(4,6)=XLS                                                      JUNCT075
      WGTS(1,5)=13.7*AREA(5)*FLCNG                                      JUNCT076
      WGTS(2,5)=AREA(5)*FLONG*RHOW*G                                    JUNCT077
      CGS(1,5)=HCL                                                      JUNCT078
      CGS(2,5)=XLS                                                      JUNCT079
      CGS(3,5)=HCL                                                      JUNCT080
      CGS(4,5)=XLS                                                      JUNCT081
      WGTS(1,ICOMP)=13.7*AJCT*AREA(ICOMP)                               JUNCT082
      WGTS(2,ICOMP)=AJCT*AREA(ICOMP)*RHOW*G                             JUNCT083
      CGS(1,ICOMP)=HCL                                                  JUNCT084
      CGS(2,ICOMP)=XLS-PO(3)*XK(3)*SIN(THATA(3)*.008757)-.5*AJCT        JUNCT085
      CGS(3,ICOMP)=HCL                                                  JUNCT086
      CGS(4,ICOMP)=CGS(2,ICOMP)                                         JUNCT087
      DEPTH=1.414*DIAM                                                  JUNCT088
      WIDTH=DEPTH                                                       JUNCT089
      RETURN                                                            JUNCT090
      END                                                               JUNCT091
```

```
      SUBROUTINE PIPE                                                   PIPE0001
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           PIPE0002
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   PIPE0003
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           PIPE0004
      COMMON /CONST/PI,G,RHOD                                           PIPE0005
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP               PIPE0006
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   PIPE0007
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)         PIPE0009
      KOUNT=ISTRT                                                       PIPE0010
      AREA(ICOMP)=AREA(ICOMP-1)                                         PIPE0011
      DIAM=1.414*SQRT(AREA(ICOMP)/PI)                                   PIPE0012
      DEPTH=DIAM                                                        PIPE0013
      WIDTH=DEPTH                                                       PIPE0014
      RO(3)=.5*DIAM                                                     PIPE0015
      APIPE=XLS-XLPE-XLP-RO(3)*XK(3)                                    PIPE0016
      IF(APIPE.LT.0.) APIPE=0.                                          PIPE0017
      XPUMP=NGT                                                         PIPE0018
      XLONG=BEAM/(XPUMP+1.)-RO(3)*XK(3)*SIN(THATA(3)*.008727)-RO(2)*    PIPE0019
     A XK(2)+RO(2)                                                      PIPE0020
    2 ICOMP=5                                                           PIPE0021
C                                                                       PIPE0022
C     FIND HEAD LOSS FOR ATHWARTSHIPS LENGTH                            PIPE0023
C                                                                       PIPE0024
      V=Q(KOUNT)/AREA(ICOMP)                                            PIPE0025
      RE=DIAM*V/GNU                                                     PIPE0026
      FRCTL=FRICT(RE)*XLONG/DIAM                                        PIPE0027
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+.5*FRCTL*V*V/G              PIPE0028
      ICOMP=6                                                           PIPE0029
C                                                                       PIPE0030
C     FIND HEAD LOSS IN PUMP ELBOW                                      PIPE0031
C                                                                       PIPE0032
      CALL ELBOW                                                        PIPE0033
C                                                                       PIPE0034
C     LOSS COEFFICIENT                                                  PIPE0035
```

```
C                                                                       PIPE0036
      ICOMP=7                                                           PIPE0037
      XKT=FRICT(RE)*APIPE/DIAM                                          PIPE0038
      DELH(KOUNT,ICOMP)=DELH(KCUNT,ICCMP-1)+.5*XKT*V*V/G                PIPE0039
      IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 1                           PIPE0040
      KOUNT=KOUNT+1                                                     PIPE0041
      GO TO 2                                                           PIPE0042
    1 AREA(ICOMP)=AREA(ICOMP-1)                                         PIPE0043
C                                                                       PIPE0044
C     CENTER OF GRAVITY AND WEIGHT CALCULATICNS OF COMPONENTS OF PUMP   PIPE0045
C     INLET PIPING                                                      PIPE0046
C                                                                       PIPE0047
      WGTS(1,5)=13.7*XLONG*AREA(5)                                      PIPE0048
      WGTS(2,5)=AREA(5)*XLCNG*RHOW*G                                    PIPE0049
      CGS(1,5)=HCL                                                      PIPE0050
      CGS(2,5)=XLS                                                      PIPE0051
      CGS(3,5)=HCL                                                      PIPE0052
      CGS(4,5)=XLS                                                      PIPE0053
      CGS(1,6)=HCL                                                      PIPE0054
      CGS(2,6)=XLS                                                      PIPE0055
      CGS(3,6)=HCL                                                      PIPE0056
      CGS(4,6)=XLS                                                      PIPE0057
      WGTS(1,ICOMP)=13.7*APIPE*AREA(ICOMP)                              PIPE0058
      WGTS(2,ICOMP)=AREA(ICCMP)*APIPE*RHOW*G                            PIPE0059
      CGS(1,ICOMP)=HCL                                                  PIPE0060
      CGS(2,ICOMP)=XLS-RO(3)*XK(3)*SIN(THATA(3)*.008727)-.5*APIPE       PIPE0061
      CGS(3,ICOMP)=HCL                                                  PIPE0062
      CGS(4,ICOMP)=CGS(2,ICCMP)                                         PIPE0063
      RETURN                                                            PIPE0064
      END                                                               PIPE0065
```

```
      SUBROUTINE DIVRG                                                  DIVRG000
      LOGICAL IFUEL,IPUMP                                               DIVRG001
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   DIVRG002
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP               DIVRG003
      COMMON /CONST/PI,G,RHOD                                           DIVRG004
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           DIVRG005
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           DIVRG006
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   DIVRG007
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /ITABL/L(2)                                                DIVRG009
      COMMON IFUEL,IPUMP                                                DIVRG010
      DIMENSION THETA(12),COEF(12)                                      DIVRG011
      DATA THETA/0.,10.,20.,30.,40.,50.,60.,70.,80.,90.,100.,110./      DIVRG012
      DATA COEF/0.005,0.04,0.18,0.36,0.57,0.77,0.955,1.14,1.3,1.42,1.5, DIVRG013
     1 1.57/                                                            DIVRG014
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)         DIVRG015
      KOUNT=ISTRT                                                       DIVRG016
      AREA(ICOMP)=AREA(ICOMP-1)                                         DIVRG017
      DIAM=1.414*SQRT(AREA(ICOMP)/PI)                                   DIVRG018
      RO(3)=.5*DIAM                                                     DIVRG019
      XPUMP=NGT+1                                                       DIVRG020
      FLONG=1.5*BEAM/XPUMP-RO(2)*XK(2)+RO(2)-RO(3)*XK(3)*SIN(THATA(3)   DIVRG021
     A *.008727)                                                        DIVRG022
C                                                                       DIVRG023
C     CENTER OF GRAVITY AND WEIGHT CALCULATIONS FOR ATHWARTSHIPS LENGTH DIVRG024
C                                                                       DIVRG025
      WGTS(1,ICOMP)=13.7*FLONG*AREA(ICOMP)                              DIVRG026
      WGTS(2,ICOMP)=AREA(ICOMP)*FLONG*RHOW*G                            DIVRG027
      CGS(1,ICOMP)=HCL                                                  DIVRG028
      CGS(2,ICOMP)=XLS                                                  DIVRG029
      CGS(3,ICOMP)=HCL                                                  DIVRG030
      CGS(4,ICOMP)=XLS                                                  DIVRG031
      RO(4)=.3535*DIAM                                                  DIVRG032
    3 ICOMP=5                                                           DIVRG033
C                                                                       DIVRG034
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```
C     GET FRICTION LOSS FOR FIRST LENGTH                                DIVRG035
C                                                                       DIVRG036
      V=Q(KOUNT)/AREA(ICOMP)                                            DIVRG037
      RE=DIAM*V/GNU                                                     DIVRG038
      FRCTL=FRICT(RE)*FLONG/DIAM                                        DIVRG039
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+FRCTL*.5*V*V/G              DIVRG040
      WIDTH=DIAM                                                        DIVRG041
      DEPTH=WIDTH                                                       DIVRG042
C                                                                       DIVRG043
C     FIND HEAD LOSS IN PUMP ELBOW                                      DIVRG044
C                                                                       DIVRG045
      ICOMP=6                                                           DIVRG046
      CALL ELBOW                                                        DIVRG047
      ICOMP=7                                                           DIVRG048
      IF(ISTRT.NE.1) ANGLE=THATA(4)*.0174533
      IF(KOUNT.NE.1) GO TO 7                                            DIVRG049
      THATA(4)=ATAN(BEAM*.5/(XPUMP*(XLS-XLPE-XLP-RO(3)*XK(3))))         DIVRG050
      ANGLE=THATA(4)                                                    DIVRG051
      XLONG=XLS-XLPE-XLP-RO(3)*XK(3)-RO(4)*XK(4)                        DIVRG052
      IF(XLONG.GT.0.) GO TO 2                                           DIVRG053
    5 XLONG=0.                                                          DIVRG054
      THATA(4)=0.                                                       DIVRG055
      WGTS(1,ICOMP)=0.                                                  DIVRG056
      ADIV=0.                                                           DIVRG057
      WGTS(2,ICOMP)=0.                                                  DIVRG058
      DIVL=0.                                                           DIVRG059
      ANGLE=0.                                                          DIVRG060
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)                             DIVRG061
      GO TO 6                                                           DIVRG062
    2 ADIV=XLONG/COS(ANGLE)                                             DIVRG063
      THATA(4)=THATA(4)*57.29578                                        DIVRG064
      IF(THATA(4).GT.90.) GO TO 5                                       DIVRG065
      DIVL=TABLE(THETA,COEF,THATA(4),L)                                 DIVRG066
    7 FRCTL=FRICT(RE*.707)*ADIV/DIAM*1.414                              DIVRG067
      DIVLC=DIVL+FRCTL                                                  DIVRG068
      HEADL=DIVLC*V*V*.5/G                                              DIVRG069
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```
      WIDTH=.707*WIDTH
      DEPTH=WIDTH
      IF(KOUNT.EQ.2) ISTRT=2
C
C     ELBOW JUST PRIOR TO PUMP INLET
C
      CALL ELBOW
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP)+HEADL
    6 IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 4
      KOUNT=KOUNT+1
      GO TO 3
    4 CGS(1,6)=HCL
      IF(KOUNT.EQ.2) ISTRT=1
C
C     CENTER OF GRAVITY AND WEIGHT CALCULATIONS OF PUMP ELBOW AND
C     TRANSITION PIECE(DIVERGENCE)
C
      CGS(2,6)=XLS
      CGS(3,6)=HCL
      CGS(4,6)=XLS
      CGS(1,ICOMP)=HCL
      CGS(3,ICOMP)=HCL
      DWGT1=WGTS(1,ICOMP)
      DWGT2=13.7*XLONG*AREA(ICOMP)
      DWGT3=DWGT1
      WWGT1=WGTS(2,ICOMP)
      WWGT2=XLONG*AREA(ICOMP)*.5*RHOW*G
      WWGT3=WWGT1
      IF(ANGLE.EQ.0.) RETURN
      CGWX1=XLS-RO(3)*XK(3)-SIN(.5*ANGLE)*RO(4)*XK(4)
      CGWX2=XLS-RO(3)*XK(3)-.5*XLONG*SIN(ANGLE)-RO(4)*XK(4)*SIN(ANGLE)
      CGWX3=XLP+XLPE+SIN(.5*ANGLE)*RO(4)*XK(4)
      CGS(2,ICOMP)=(DWGT1*CGWX1+DWGT2*CGWX2+DWGT3*CGWX3)/(DWGT1+DWGT2+DW
     1GT3)
      CGS(4,ICOMP)=(WWGT1*CGWX1+WWGT2*CGWX2+WWGT3*CGWX3)/(WWGT1+WWGT2+
     1 WWGT3)
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      WGTS(1,ICOMP)=DWGT1+DWGT2+DWGT3                                   DIVRG106
      WGTS(2,ICOMP)=WWGT1+WWGT2+WWGT3                                   DIVRG107
      RETURN                                                            DIVRG108
      END                                                               DIVRG109
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```
      SUBROUTINE NOZZL                                                  NOZZL000
      LOGICAL IFUEL,IPUMP                                               NOZZL001
      REAL JANGL
      COMMON /NOZL/JANGL
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),     NOZZL002
     1 TRIM(5)                                                          NOZZL003
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   NOZZL004
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           NOZZL005
      COMMON /CONST/PI,G,RHOD                                           NOZZL006
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP               NOZZL007
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   NOZZL008
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON IFUEL,IPUMP                                                NOZZL010
      DIMENSION QQ(5)                                                   NOZZL011
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)         NOZZL012
      KOUNT=ISTRT                                                       NOZZL013
      XLPS=XLPE                                                         NOZZL014
      XFAC=1.4*HCL/XLPE                                                 NOZZL015
      XPUMP=NPUMP                                                       NOZZL016
      IF(.NOT.IPUMP) AREA(8)=AREA(7)                                    NOZZL017
      AREA(ICOMP)=AJET                                                  NOZZL018
      IF(ISTRT.EQ.1) ANOZ=ATAN(TDRAG(1)/DISP)
      IF(ISTRT.NE.1) ANOZ=JANGL
C                                                                       NOZZL020
C     XFAC.LT.1. INDICATES NOZZLE EXITS THROUGH BOTTOM                  NOZZL021
C                                                                       NOZZL022
      IF(XFAC.LT.1.) XLPS=1.4*HCL                                       NOZZL023
      XLNOZ=XLPS/COS(ANOZ)                                              NOZZL024
      DT=2.*SQRT(AREA(ICOMP-1)/(PI*XPUMP))                              NOZZL025
      DJ=2.*SQRT(AJET/(PI*XPUMP))                                       NOZZL026
      IF(DT.LT.DJ) GO TO 3                                              NOZZL027
    1 QQ(KOUNT)=Q(KOUNT)/XPUMP                                          NOZZL028
      XCORR=XLNOZ/(DT-DJ)*(1.-(2./(1.+DT/DJ))**4)*VJ(KOUNT)*VJ(KOUNT)/G*NOZZL029
     11.25                                                              NOZZL030
      RE=8.*QQ(KOUNT)/(PI*(DT+DJ)*GNU)                                  NOZZL031
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      IF(DJ.LT.1.) XCORR=.0075*VJ(KCUNT)**2/(G*FRICT(RE))                    NOZZL032
      IF(ABS(DT-DJ).LT..01) XCORR=XLNOZ/(G*(DT+DJ))*( Q(KOUNT)/              NOZZL033
     A (AREA(ICOMP-1)+AJET)*.5)**2                                           NOZZL034
      DELH(KOUNT,8)=XCORR*FRICT(RE)-XLNOZ*SIN(ANOZ)                          NOZZL035
      IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 2                                NOZZL036
      KOUNT=KOUNT+1                                                          NOZZL037
      GO TO 1                                                                NOZZL038
    3 WGTS(1,ICOMP)=1.E9
      RETURN                                                                 NOZZL040
C                                                                            NOZZL041
C     CENTER OF GRAVITY AND WEIGHT CALCULATIONS OF NOZZLE                    NOZZL042
C                                                                            NOZZL043
    2 CGS(1,ICOMP)=HCL                                                       NOZZL044
      CGS(2,ICOMP)=XLPE-XLPS*(.25*DT*DT+.5*DT*DJ+.75*DJ*DJ)/(DT*DT+DT*DJNOZZL045
     A +DJ*DJ)                                                               NOZZL046
      CGS(3,ICOMP)=HCL                                                       NOZZL047
      CGS(4,ICOMP)=CGS(2,ICOMP)                                              NOZZL048
      WGTS(2,ICOMP)=XLPS/3.*(AREA(ICOMP-1)+AJET+SQRT(AREA(ICOMP-1)*AJET)NOZZL049
     A   )*RHOW*G                                                            NOZZL050
      AREA1=PI*.25*(.152*DT+.056**2)                                         NOZZL051
      AJET1=PI*.25*(.152*DJ+.056**2)                                         NOZZL052
      WGTS(1,ICOMP)=XLPS/3.*(AREA1+AJET1+SQRT(AREA1*AJET1))*RHOD*G*XPUMPNOZZL053
      IF(XFAC.GT.1.) RETURN                                                  NOZZL054
      CGS(1,ICOMP)=.75*HCL                                                   NOZZL055
      CGS(3,ICOMP)=CGS(1,ICOMP)                                              NOZZL056
      RETURN                                                                 NOZZL057
      END                                                                    NOZZL058
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      SUBROUTINE PUMP                                                   PUMP 000
C                                                                       PUMP 001
C     PUMP JET DESIGN PROGRAM                                           PUMP 002
C                                                                       PUMP 003
C     PUMP JET PROGRAM SOLVES THE PUMP, GEAR , AND FUEL WEIGHTS FOR     PUMP 004
C       BOTH THE MULT-PARALLEL CENTRIFUGAL PUMP AND THE AXIAL PUMP      PUMP 005
C     THE PUMP DESIGN WITH THE LEAST TOTAL WEIGHT IS GIVEN AS THE       PUMP 006
C     OPTIMUM DESIGN FOR THE GIVEN INPUT PARAMETERS                     PUMP 007
C                                                                       PUMP 008
      LOGICAL I605L,IPUMP,TYGER
      COMMON /WARN/CAV(5,6)
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           PUMP 010
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),     PUMP 011
     1 TRIM(5)                                                          PUMP 012
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   PUMP 013
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP              PUMP 014
      COMMON /CONST/PI,G,RHOD                                           PUMP 015
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   PUMP 016
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /WEGT/XWD(5),XWW(5),XWG(5),XWF(5)                          PUMP 018
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)      PUMP 019
      COMMON /PUMM/QG(5),D1S(5),D2S(5),XNS(5),SM(5,5),PLP(5),NSTG,SHI(5,
     A5),XIM
      COMMON /HEAD/HPP(5),HSV(5),THCM(5),PHI(5,5),WF,WG,FRATE(5)
      COMMON /TOLER/DELTA                                               PUMP 023
      COMMON IFUEL,IPUMP,TYGER
      DIMENSION PC(2,3),PCA(2,3),PCC(2,3)                               PUMP 025
      DIMENSION  XPPM(11),XD1(11),XD2(11),RPK(11),XPUP(11),YLP(11),     PUMP 026
     6XERAT(11),APUP(5),WRAT(5),WD(10),WW(10),WWG(10)                   PUMP 027
C                                                                       PUMP 028
C     PUMP CHARCTERISTIC DATA                                           PUMP 029
      DATA PC/-3.0,-1.7,4.8,3.42,-0.8,-0.720/                           PUMP 030
      DATA PCA/-1.0,-1.7,1.0,3.42,1.0,-0.72/                            PUMP 031
      DATA PCC/-1.5,-0.75,1.0,1.51,1.0,0.24/                            PUMP 032
C                                                                       PUMP 033
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C     K = CRUISE POINT  , J = TAKE OFF POINT                            PUMP 034
C     PUMP DESIGN POINT,J, IS AT TAKE OFF BASED ON THOMA'S CRITERION    PUMP 035
C     OFF DESIGN POINT,K, IS ANY OTHER POINT ALONG THE DRAG TO SPEED CURPUMP 036
      K=1                                                               PUMP 037
      J=2                                                               PUMP 038
      DO 4 I=1,5                                                        PUMP 039
    4 WPAT(I)=0.                                                        PUMP 040
      XPUMP=FLOAT(NPUMP)                                                PUMP 041
      QQ(J)=Q(J)/XPUMP
      JNUMB=NUMB
      IF(ISTRT.EQ.1) JNUMB=2
      DO 2 I=ISTRT,JNUMB
      QQ(I)=Q(I)/XPUMP                                                  PUMP 043
      HPP(I)=(VJ(I)*VJ(I)-VO(I)*VO(I))/(2.*G)+DELH(I,7)+DELH(I,8)       PUMP 044
      HSV(I)=HA-DELH(I,7)+VO(I)*VO(I)/(2.*G)-PV                         PUMP 045
      THOM(I)=HSV(I)/HPP(I)                                             PUMP 046
    2 CONTINUE                                                          PUMP 047
      IF(ISTRT.EQ.3) GO TO(200,401,401,300),NSTG
      NSTG=1                                                            PUMP 048
      IF(HSV(J).LT.0.005)  GO TO 10                                     PUMP 049
C                                                                       PUMP 050
C     FOR THE VALUE ON THOMA'S CAVITATION CRITERION LESS THAN THE CUT   PUMP 051
C     OFF POINT, THOMI, THE INDUCER PLUS ONE AXIAL STAGE IS REQUIRED    PUMP 052
C                                                                       PUMP 053
      THOMI=0.055                                                       PUMP 054
      IF(THOM(J).LT.THOMI)  GO TO 201                                   PUMP 055
C                                                                       PUMP 056
C     SINGLE STAGE INDUCER DESIGN                                       PUMP 057
C     PUMP CHARACTERISTICS                                              PUMP 058
C     XNS IS THE SPECIFIC SPEED (CFS) FOR THE FIRST STAGE IN A MULTI-STAPUMP 059
C     DESIGN OR FOR ONE IMPELLER IN A MULTI-DOUBLE SUCTION IMPELLER DESIPUMP 060
C     SM IS THE MAXIMUM SUCTION SPECIFIC SPEED AT TAKE OFF .            PUMP 061
C                                                                       PUMP 062
  200 XNS(NSTG)=149.5                                                   PUMP 063
      IF(ISTRT.NE.3) SM(2,1)=XNS(1)*(1.0/THOM(J))**0.75
      PHI(2,1)=0.11
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      DRAT=0.30                                                         PUMP 066
      XXLP=1.79                                                         PUMP 067
      CW=347.1*XPUMP                                                    PUMP 068
      IF(ISTRT.EQ.3)GO TO 402
C                                                                       PUMP 069
C     DESIGN POINT PUMP SPEED                                           PUMP 070
C                                                                       PUMP 071
      RPM(J,NSTG)=XNS(NSTG)*HPP(J)**0.75/SQRT(QQ(J))                    PUMP 072
C                                                                       PUMP 073
C     PUMP INLET TIP DIAMETER                                           PUMP 074
C                                                                       PUMP 075
      DIS(1)=(240.*QQ(J)/(9.4748*PHI(2,1)*(1.-DRAT**2)*RPM(J,1)))**(1./3
     1.)
      SHI(2,1)=G*HPP(J)/(PI*RPM(J,1)*DIS(1)/60.)**2
      IF(SHI(2,NSTG).GT.0.41) GO TO 201
  402 ETAP(J,NSTG)=1.0-((3.666/DIS(NSTG))**0.165*(1.-.915))
      JNUMB=NUMB
      IF(ISTRT.EQ.1) JNUMB=1
      DO 403 K=ISTRT,JNUMB
      QX=QQ(K)/QQ(J)                                                    PUMP 080
      ETAX=PC(2,1)*QX**2+PC(2,2)*QX+PC(2,3)
      IF(ETAX.LE.0.) ETAX=0.001
      ETAP(K,NSTG)=ETAP(J,NSTG)*ETAX
C                                                                       PUMP 082
C     OFF DESIGN POINT PUMP RPM                                         PUMP 083
C                                                                       PUMP 084
      CA=PC(1,2)/PC(1,3)*0.5                                            PUMP 085
      CB=PC(1,1)/PC(1,3)                                                PUMP 086
      HX=HPP(K)/HPP(J)                                                  PUMP 087
      RX=-CA*QX-SQRT(QX*QX*(CA*CA-CB)+HX/PC(1,3))                       PUMP 088
      RPM(K,NSTG)=RPM(J,NSTG)*RX                                        PUMP 089
C                                                                       PUMP 090
C     PHRAT IS THE OFF DESIGN TO DESIGN FLOW COEFFICIENT RATIO, PHI(K)/PPUMP 091
C                                                                       PUMP 092
      PHRAT=QX/RX                                                       PUMP 093
C                                                                       PUMP 094
```

```
      IF(ISTRT.EQ.1)GO TO 403
      SHI(K,NSTG)=G*HPP(K)/(PI*RPM(K,NSTG)*D1S(NSTG)/60.)**2
      PHI(K,NSTG)=PHRAT*PHI(2,NSTG)
      SM(K,NSTG)=RPM(K,NSTG)*SQRT(QQ(K))/HSV(K)**0.75
  403 CONTINUE
C     DRY PUMP WEIGHT                                                   PUMP 095
C                                                                       PUMP 096
  203 XWD(NSTG)=CW*D1S(NSTG)**2.3                                       PUMP 097
      PLP(NSTG)=D1S(NSTG)*XXLP                                          PUMP 098
      APUP(NSTG)=0.785*D1S(NSTG)**2*(1.-DRAT*DRAT)                      PUMP 099
      D2S(NSTG)=D1S(NSTG)                                               PUMP 100
C                                                                       PUMP 101
C     ENTRAINED WATER WEIGHT                                            PUMP 102
C                                                                       PUMP 103
      XWW(NSTG)=0.523*APUP(NSTG)*PLP(NSTG)*RHOW*G*XPUMP                 PUMP 104
      XNGT=NGT                                                          PUMP 105
      IF(ISTRT.EQ.3)GO TO 404
      SHP(2,NSTG)=RHOW*G*Q(2)*HPP(2)/(550.*XNGT*ETAP(2,NSTG)*.98)       PUMP 106
      GERAT(NSTG)=PERF(4,IENGN)/RPM(J,NSTG)                             PUMP 107
      IF(GERAT(NSTG).LT..95) GO TO 16
  404 IF(ISTRT.EQ.3)SHP(2,NSTG)=PERF(1,IENGN)
      CALL GEAR                                                         PUMP 109
      XWG(NSTG)=WG                                                      PUMP 110
      JNUMB=NUMB
      IF(ISTRT.EQ.1) JNUMB=2
      DO 3 I=ISTRT,JNUMB
      ETAPP=ETAP(I,NSTG)*ETAP(7,NSTG)                                   PUMP 112
      SHP(I,NSTG)=RHOW*G*Q(I)*HPP(I)/(550.*XNGT*ETAPP)                  PUMP 113
    3 IF(SHP(I,NSTG).GT.PERF(I,IENGN).AND.DELTA.GT.1.E-9) XWW(NSTG)=1.E9PUMP 114
C                                                                       PUMP 115
      CALL FUEL                                                         PUMP 116
      XWF(NSTG)=WF                                                      PUMP 117
      WRAT(NSTG)=(XWD(NSTG)+XWW(NSTG)+XWG(NSTG)+XWF(NSTG))/DISP         PUMP 118
      IF(ISTRT.EQ.3)GO TO 410
      GO TO 300                                                         PUMP 119
   16 XWG(NSTG)=1.E9
```

```
      GO TO 300                                                         PUMP 121
C                                                                       PUMP 122
C     INDUCER PLUS ONE AXIAL STAGE DESIGN                               PUMP 123
C                                                                       PUMP 124
  201 THOMI=0.058                                                       PUMP 125
      NSTG=2                                                            PUMP 126
      HP=HSV(J)/THOMI                                                   PUMP 127
C                                                                       PUMP 128
C     THOMS IS THOMA'S CAVITATICN CRITERICN FCR THE AXIAL STAGE         PUMP 129
C     BASED ON A MAXIMUM  S OF 10,000 AND NS=3619                       PUMP 130
C                                                                       PUMP 131
      THOMS=0.258                                                       PUMP 132
C                                                                       PUMP 133
C     INDUCER SPECIFIC SPEED ANC FLCW COEFF.                            PUMP 134
C                                                                       PUMP 135
  401 XNS(NSTG)=149.5
      PHI(2,2)=0.15
      DRAT=C.3                                                          PUMP 138
      XXLP=1.71                                                         PUMP 139
      CW=393.5*XPUMP                                                    PUMP 140
      IF(NSTG.EQ.3) XXLP=2.03
      IF(NSTG.EQ.3) CW=439.5*XPUMP
      IF(ISTRT.EQ.3)GO TO 405
C                                                                       PUMP 141
C     DESIGN PUMP SPEED                                                 PUMP 142
C                                                                       PUMP 143
      RPM(J,NSTG)=XNS(NSTG)*HP**0.75/SQRT(QQ(J))                        PUMP 144
C                                                                       PUMP 145
C     PUMP INLET TIP CIAMETER                                           PUMP 146
C                                                                       PUMP 147
      D1S(2)=(240.*QQ(J)/(9.4748*PHI(2,2)*(1.-DRAT**2)*RPM(J,2)))**(1./
     13.)
  405 ETAP(J,NSTG)=1.0-((3.666/D1S(NSTG))**0.165*(1.-.915))
      JNUMB=NUMB
      IF(ISTRT.EQ.1) JNUMP=1
      DO 406 K=ISTRT,JNUMB
```

```
      QX=QQ(K)/QQ(J)                                                    PUMP 150
      ETAX=PCA(2,1)*QX**2+PCA(2,2)*QX+PCA(2,3)
      IF(ETAX.LE.0.) ETAX=0.001
      ETAP(K,NSTG)=ETAP(J,NSTG)*ETAX
C                                                                       PUMP 152
C     OFF DESIGN POINT RPM                                              PUMP 153
C                                                                       PUMP 154
      CA=PCA(1,2)/PCA(1,3)*0.5                                          PUMP 155
      CB=PCA(1,1)/PCA(1,3)                                              PUMP 156
      HX=HPP(K)/HPP(J)                                                  PUMP 157
      RX=-CA*QX+SQRT(QX*QX*(CA*CA-CB)+HX/PCA(1,3))*(CA/ABS(CA))         PUMP 158
      RPM(K,NSTG)=RPM(J,NSTG)*RX                                        PUMP 159
      PHRAT=QX/RX                                                       PUMP 160
      PHI(K,NSTG)=PHRAT*PHI(2,NSTG)
      IF(ISTRT.NE.3)GO TO 406
      SM(K,NSTG)=RPM(K,NSTG)*SQRT(QQ(K))/HSV(K)**0.75
      SHI(K,NSTG)=G*HPP(K)/(PI*RPM(K,NSTG)*DIS(NSTG)/60.)**2
      PHI(K,NSTG)=PHRAT*PHI(2,NSTG)
  406 CONTINUE
      IF(ISTRT.EQ.3) GO TO 203
      SM(2,NSTG)=XNS(NSTG)*(HP/HSV(J))**0.75
      IF((HSV(J)+HP)/(HPP(J)-HP).LT.THOMS)  GO TO 202                   PUMP 162
      SHI(2,NSTG)=G*HP/(PI*RPM(J,2)*DIS(2)/60.)**2
      GO TO 203                                                         PUMP 164
C                                                                       PUMP 165
C     INDUCER PLUS TWO AXIAL STAGES DESIGN                              PUMP 166
C                                                                       PUMP 167
  202 HHP=(HPP(J)-HP)/2.0                                               PUMP 168
      NSTG=3                                                            PUMP 169
      XXLP=2.03                                                         PUMP 170
      CW=439.5*XPUMP                                                    PUMP 171
      XNS(3)=XNS(2)                                                     PUMP 172
      SM(2,3)=SM(2,2)
      DIS(3)=DIS(2)                                                     PUMP 174
      SHI(2,3)=SHI(2,2)
      PHI(2,3)=PHI(2,2)
```

```
      RPM(J,3)=RPM(J,2)                                                 PUMP 177
      RPM(K,3)=RPM(K,2)                                                 PUMP 178
      ETAP(J,3)=ETAP(J,2)                                               PUMP 179
      ETAP(K,3)=ETAP(K,2)                                               PUMP 180
      IF(((HSV(J)+HP)/HHP).LT.THOMS)  GO TO 10                          PUMP 181
      GO TO 203                                                         PUMP 182
C                                                                       PUMP 183
C     MULTI PARALLEL IMPELLER DESIGN                                    PUMP 184
C                                                                       PUMP 185
  300 NSTG=4                                                            PUMP 186
      SM(2,NSTG)=424.5
C                                                                       PUMP 188
C     PUMP CHARACTERISTICS.                                             PUMP 189
C     THE CENTRIFUGAL IMPELLER DESIGN IS BASED ON A CONSTANT IMPELLER   PUMP 190
C     EXIT ANGLE OF 22 DEGREES AND A HYDRAULIC EFFICIENCY OF 0.90       PUMP 191
C                                                                       PUMP 192
      DRAT=0.50                                                         PUMP 193
      BETA2=2.477                                                       PUMP 194
      IF(ISTRT.NE.3)XNS(4)=SM(2,4)*THOM(J)**0.75
      IF(ISTRT.EQ.3) XNS(4)=RPM(J,NSTG)*SQRT(QQ(J))/HPP(J)**0.75
      XNNS=XNS(4)/811.3                                                 PUMP 196
C                                                                       PUMP 197
C     THE IMPELLER EXIT WIDTH RATIO IS ASSUMMED TO BE LINEAR WITH NS    PUMP 198
C                                                                       PUMP 199
      BD=0.001*XNS(4)-0.025                                             PUMP 200
      IF(XNS(4).LT.50.)  BD=0.025                                       PUMP 201
      CC=SQRT(BD/PI)                                                    PUMP 202
      PHI(2,4)=0.06
   14 AA=CC*SQRT(PHI(2,4))/(0.9*(1.-PHI(2,4)*BETA2))**0.75
      IF((XNNS-AA).LE.0.005)  GO TO 15                                  PUMP 205
      PHI(2,4)=PHI(2,4)+0.005
      GO TO 14                                                          PUMP 207
   15 SHI(2,4)=0.90*(1.-PHI(2,4)*2.414)
C                                                                       PUMP 209
C     SPECIFIC SPEED AND PUMP CHARAC. ARE FOR A SINGLE IMPELLER         PUMP 210
C                                                                       PUMP 211
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      PCC(1,3)=XNS(4)/283.85-.17                                        PUMP 212
      PCC(1,2)=2.5-PCC(1,3)                                             PUMP 213
      IF(ISTRT.EQ.3)GO TO 407
C                                                                       PUMP 214
      IMPL=10                                                           PUMP 215
      DO5 M=1,IMPL                                                      PUMP 216
C     XIM EQUALS THE NUMBER OF DOUBLE SUCTION IMPELLERS                 PUMP 217
      XIM=FLOAT(M)                                                      PUMP 218
      QQ(J)=Q(J)/(2.0*XIM*XPUMP)                                        PUMP 219
      QQ(K)=Q(K)/(2.0*XIM*XPUMP)                                        PUMP 220
      QX=QQ(K)/QQ(J)                                                    PUMP 221
      XRPM(M)=XNS(4)*HPP(J)**0.75/SQRT(QQ(J))                           PUMP 222
      XD1(M)=(240.*QQ(J)/(9.4748*0.2500*(1.-DRAT**2)*XRPM(M)))**(1./3.) PUMP 223
      XD2(M)=60.0*SQRT(G*HPP(J)/SHI(2,4))/(PI*XRPM(M))
C     OFF DESIGN POINT RPM                                              PUMP 225
      CA=PCC(1,2)/PCC(1,3)*0.5                                          PUMP 226
      CB=PCC(1,1)/PCC(1,3)                                              PUMP 227
      HX=HPP(K)/HPP(J)                                                  PUMP 228
      RX=-CA*QX+SQRT(QX*QX*(CA*CA-CB)+HX/PCC(1,3))*(CA/ABS(CA))         PUMP 229
      RPK(M)=XRPM(M)*RX                                                 PUMP 230
C                                                                       PUMP 231
      ETAP(J,4)=1.0-((2.333/XD2(M))**0.165*(1.-.880))                   PUMP 232
      ETAX=PCC(2,1)*QX**2+PCC(2,2)*QX+PCC(2,3)
      IF(ETAX.LE.0.) ETAX=0.001
      ETAP(K,NSTG)=ETAP(J,NSTG)*ETAX
C                                                                       PUMP 234
C     PUMP WEIGHT                                                       PUMP 235
C                                                                       PUMP 236
      XPUP(M)=101.91*Q(J)/(XRPM(M)*XD1(M)*XPUMP)                        PUMP 237
      YLP(M)=SQRT(XPUP(M)/(XIM*0.866))*(1.+XIM)                         PUMP 238
      CW=4.66                                                           PUMP 239
      WD(M)=(XIM*.725+.275)*CW*XD2(M)*XD2(M)*XNS(4)*XPUMP               PUMP 240
      WW(M)=0.55*WD(M)                                                  PUMP 241
C                                                                       PUMP 242
C                                                                       PUMP 243
      SHP(2,NSTG)=RHOW*G*Q(2)*HPP(2)/(550.*XNGT*ETAP(2,NSTG)*.98)       PUMP 244
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```
      XERAT(M)=PERF(4,IENGN)/XRPM(M)                                   PUMP 245
      GERAT(4)=XERAT(M)                                                PUMP 246
      CALL GEAR                                                        PUMP 247
      WWG(M)=WG                                                        PUMP 248
      DO7 I=1,2                                                        PUMP 249
      ETAPP=ETAP(I,NSTG)*ETAP(7,NSTG)                                  PUMP 250
      SHP(I,NSTG)=RHCW*G*Q(I)*HPP(I)/(550.*XNGT*ETAPP)                 PUMP 251
    7 IF(SHP(I,NSTG).GT.PERF(I,IENGN).AND.DELTA.GT.1.E-9) WW(M)=1.E9   PUMP 252
      IF(M.EQ.1) GO TO 5                                               PUMP 253
      IF(THOM(J).LT.0.046)  GO TO 12                                   PUMP 254
      IF(XERAT(M).LE.1.0)  GO TO 6                                     PUMP 255
      IF((WD(M)+WW(M)+WWG(M)).GT.(WD(M-1)+WW(M-1)+WWG(M-1))) GO TO 6   PUMP 256
    5 CONTINUE                                                         PUMP 257
      M=IMPL+1                                                         PUMP 258
      GO TO 6                                                          PUMP 259
   12 WD(M-1)=1.E9                                                     PUMP 260
    6 XWD(4)=WD(M-1)                                                   PUMP 261
      XWW(4)=WW(M-1)                                                   PUMP 262
      XWG(4)=WWG(M-1)                                                  PUMP 263
      XIM=M-1                                                          PUMP 264
      RPM(J,4)=XRPM(M-1)                                               PUMP 265
      D1S(4)=XD1(M-1)                                                  PUMP 266
      D2S(4)=XD2(M-1)                                                  PUMP 267
      RPM(K,4)=PPK(M-1)                                                PUMP 268
      APUP(4)=XPUP(M-1)                                                PUMP 269
      PLP(4)=YLP(M-1)                                                  PUMP 270
      GERAT(4)=XERAT(M-1)                                              PUMP 271
      IF(GERAT(4).LT..95) XWG(4)=1.E9
      IF(ISTRT.NE.3)GO TO 408
  407 DO 409 K=ISTRT,NUMB
      QQ(K)=QQ(K)/(XIM*2.0)
      QQ(J)=QQ(J)/(XIM*2.0)
      QX=QQ(K)/QQ(J)
      RPM(J,NSTG)=XNS(NSTG)*HPP(J)**0.75/SQRT(QQ(J))
      CA=PCC(1,2)/PCC(1,3)*0.5
      CB=PCC(1,1)/PCC(1,3)
```

```
      HX=HPP(K)/HPP(J)
      RX=-CA*QX+SQRT(QX*QX*(CA*CA-CB)+HX/PCC(1,3))*(CA/ABS(CA))
      RPM(K,NSTG)=RPM(J,NSTG)*RX
      ETAP(J,NSTG)=1.0-((2.333/D2S(NSTG))**0.165*(1.-.880))
      ETAX=PCC(2,1)*QX**2+PCC(2,2)*QX+PCC(2,3)
      IF(ETAX.LE.0.) ETAX=0.001
      ETAP(K,NSTG)=ETAP(J,NSTG)*ETAX
      PHRAT=QX/RX
      PHI(K,NSTG)=PHRAT*PHI(2,NSTG)
      SHI(K,NSTG)=G*HPP(K)/(PI*RPM(K,NSTG)*D2S(NSTG)/60.)**2
  409 CONTINUE
      APUP(NSTG)=101.91*Q(J)/(RPM(J,NSTG)*D1S(NSTG)*XPUMP)
      PLP(NSTG)=SQRT(APUP(NSTG)/(XIM*0.866))*(1.+XIM)
      CW=4.66
      XWD(NSTG)=(XIM*.725+.275)*CW*D2S(NSTG)*D2S(NSTG)*XNS(NSTG)*XPUMP
      XWW(NSTG)=0.55*XWD(NSTG)
      SHP(2,NSTG)=PERF(1,IENGN)
      CALL GEAR
      XWG(NSTG)=WG
      DO 411 I=ISTRT,NUMB
      ETAPP=ETAP(I,NSTG)*ETAP(7,NSTG)
      SHP(I,NSTG)=RHOW*G*Q(I)*HPP(I)/(550.*XNGT*ETAPP)
  411 CONTINUE
  408 CONTINUE
      CALL FUEL
      XWF(4)=WF
C
C     TOTAL WEIGHT TO DISPLACEMENT RATIO
C
      WRAT(NSTG)=(XWD(NSTG)+XWW(NSTG)+XWG(NSTG)+XWF(NSTG))/DISP
      IF(ISTRT.EQ.3)GO TO 410
      N=4
      DO8  M=1,3
      IF(WRAT(M).NE.0.) GO TO 9
    8 CONTINUE
    9 CONTINUE
```

```
      IF(WRAT(M).GT.WRAT(N)) M=N                                        PUMP 284
      NSTG=M                                                            PUMP 285
  410 M=NSTG                                                            PUMP 286
      XLP=PLP(NSTG)                                                     PUMP 287
      IPUMP=.NOT.IPUMP                                                  PUMP 288
      WGTS(1,8)=XWD(M)                                                  PUMP 289
      WGTS(2,8)=XWW(M)                                                  PUMP 290
      WGTS(1,10)=XWG(M)                                                 PUMP 291
      WGTS(2,11)=XWF(M)                                                 PUMP 292
      CGS(1,ICOMP)=HCL                                                  PUMP 293
      CGS(2,ICOMP)=XLPE+XLP*.5                                          PUMP 294
      CGS(3,ICOMP)=HCL                                                  PUMP 295
      CGS(4,ICOMP)=CGS(2,ICOMP)                                         PUMP 296
      AREA(8)=APUP(NSTG)*XPUMP                                          PUMP 297
      IF(NSTG.NE.4) XIM=NSTG-1                                          PUMP 298
      RETURN
   10 WGTS(1,8)=1.E9                                                    PUMP 300
      RETURN                                                            PUMP 301
      END
```

```
      SUBROUTINE GEAR                                                   GEAR 000
      LOGICAL IFUEL,IPUMP,TYGER
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /CONST/PI,G,RHOD                                           GEAR 002
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)      GEAR 003
      COMMON /PUMM/QQ(5),D1S(5),D2S(5),XNS(5),SM(5,5),PLP(5),NSTG,SHI(5,
     A5),XIM
      COMMON /HEAD/HPP(5),HSV(5),THCM(5),PHI(5,5),WF,WG,FRATE(5)
      COMMON IFUEL,IPUMP,TYGER
C                                                                       GEAR 007
C     GEAR PUMP ARRANGEMENT.  IF NO. OF PUMPS =S NO. OF GTS , A PLANETARGEAR 008
C     WILL BE USED.  IF TWO PUMPS PER GT OR TWO GTS PER  PUMP A COMBININGEAR 009
C     REDUCTION GEAR WITH IDLER WILL BE USED.                           GEAR 010
C                                                                       GEAR 011
      GRAT=GERAT(NSTG)                                                  GEAR 012
      IF(TYGER) GO TO(20,101,12),IGEAR
      IF(GRAT.GT.12.)  GO TO 12                                         GEAR 013
      IF(NGT-NPUMP) 100,101,102                                         GEAR 014
   20 IF(NGT-NPUMP) 100,106,102
C                                                                       GEAR 015
C     SUBROUTINE FOR SINGLE REDUCTION GEAR WITH IDLER                   GEAR 016
C                                                                       GEAR 017
  100 FAC=1.7                                                           GEAR 018
      GO TO 3                                                           GEAR 019
  106 FAC=1.0
      GO TO 3
  102 FAC=1.3                                                           GEAR 020
    3 IF(GRAT.GT.1.0) GO TO 1                                           GEAR 021
      GRAT=1.0                                                          GEAR 022
    1 C=GRAT*GRAT+1.0                                                   GEAR 023
      D=SQRT(C*C/64.0+0.00463)                                          GEAR 024
      DX=C*0.25-D                                                       GEAR 025
      X=(C*0.25+D)**(1.0/3.0)+DX/ABS(DX)*ABS(DX)**(1.0/3.0)             GEAR 026
      FD=(1.0+GRAT**2.0)*(1.0+1.0/X)+X*(1.0+X)                          GEAR 027
      WG=FAC*88.2*FD*SHP(2,NSTG)/PERF(4,IENGN)*ABS(FLOAT(NGT-NPUMP))    GEAR 028
```

```
      ETAP(7,NSTG)=0.98                                                 GEAR 029
      GO TO 2                                                           GEAR 030
C                                                                       GEAR 031
C     SUBROUTINE FOR PLANETARY GEAR WEIGHT                              GEAR 032
C     ASSUMED. K FACTOR = 500                                           GEAR 033
C     ALLOCATION FACTOR = 0.35                                          GEAR 034
C                                                                       GEAR 035
  101 IF(GRAT.GT.1.5)  GO TO 8                                          GEAR 036
      WG=0.0                                                            GEAR 037
      ETAP(7,NSTG)=1.0                                                  GEAR 038
      GO TO 2                                                           GEAR 039
    8 IF(GRAT.GT.2.05)  GO TO 9                                         GEAR 040
      GRAT=2.05                                                         GEAR 041
    9 IF(GRAT.GT.4.0)  GO TO 10                                         GEAR 042
      B=6.0                                                             GEAR 043
      GO TO 11                                                          GEAR 044
   10 B=PI/ARSIN((GRAT-2.0)/GRAT)                                       GEAR 045
   11 C=0.4*(GRAT-1.0)*(GRAT-1.0)                                       GEAR 046
      E=(C+1.0)/B*0.5                                                   GEAR 047
      D=SQRT(.25*(.25/27.-E)**2-1./43856.)                              GEAR 048
      DX=-(.25/27.-E)*0.5-D                                             GEAR 049
      X=(-(.25/27.-E)*.5+D)**(1./3.)+DX/ABS(DX)*ABS(DX)**(1./3.)        GEAR 050
      FD=1./B*(1.+1./X)*(1.+X*X*B+C)                                    GEAR 051
      WG=88.2*FD*SHP(2,NSTG)/PERF(4,IENGN)*FLOAT(NPUMP)                 GEAR 052
      ETAP(7,NSTG)=0.98                                                 GEAR 053
      GO TO 2                                                           GEAR 054
C                                                                       GEAR 055
C     DOUBLE REDUCTION DOUBLE BRANCH GEAR DESIGN                        GEAR 056
C     GEAR BASED ON A K FACTOR OF 300                                   GEAR 057
C                                                                       GEAR 058
   12 IF(NGT-NPUMP)  103,104,105                                        GEAR 059
  103 FAC=1.7*FLOAT(NPUMP-NGT)                                          GEAR 060
      GO TO 13                                                          GEAR 061
  104 FAC=1.0*FLOAT(NPUMP)                                              GEAR 062
      GO TO 13                                                          GEAR 063
  105 FAC=1.3*FLOAT(NGT-NPUMP)                                          GEAR 064
```

```
13 A=GRAT/(GRAT+1.0)                                                  GEAR 065
   C=(GRAT*GRAT+1.0)*0.25                                             GEAR 066
   D=SQRT((2.*A**3/27.-A*C)**2*.25-A**6/729.)                         GEAR 067
   E=-2.*A**3/27.+A*C                                                 GEAR 068
   DX=(E-D)**(1./3.)                                                  GEAR 069
   X=(E+D)**(1./3.)+DX/ABS(DX)*ABS(DX)**(1./3.)                       GEAR 070
   FD=.5*(1.+1./X+4.*X+2.*X*X*(1.+1./GRAT)+2.*GRAT*GRAT/X+GRAT)       GEAR 071
   WG=FAC*147.*FD*SHP(2,NSTG)/PERF(4,IENGN)                           GEAR 072
   ETAP(7,NSTG)=0.93                                                  GEAR 073
 2 CONTINUE                                                           GEAR 074
   RETURN                                                             GEAR 075
   END                                                                GEAR 076
```

```
      SUBROUTINE FUEL                                                   FUEL 000
C     FUEL WEIGHT AT CONSTANT SPEED ASSUMMING SFC = CSF*SHP TO 1/4 AND EFUEL 001
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           FUEL 002
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   FUEL 003
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),     FUEL 004
     1 TRIM(5)                                                          FUEL 005
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP              FUEL 006
      COMMON /CONST/PI,G,RHOD                                           FUEL 007
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   FUEL 008
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)      FUEL 010
      COMMON /PUMM/QQ(5),D1S(5),D2S(5),XNS(5),SM(5,5),PLP(5),NSTG,SHI(5,
     A5),XIM
      COMMON /HEAD/HPP(5),HSV(5),THCM(5),PHI(5,5),WF,WG,FRATE(5)
      DIMENSION WT(21),DIS(21),VJJ(21)                                  FUEL 014
      IF(ISTRT.EQ.3)GO TO 10
C                                                                       FUEL 015
C     FUEL CALCULATIONS BASED ON CONSTANT SPEED THROUGHOUT RANGE. DURATIFUEL 016
C     TRAVEL DIVIDED INTO 20 SEGMENTS AND FUEL WEIGHT CALCULATED ON REVIFUEL 017
C     SHP REQUIREMENTS DUE TO WEIGHT DECREASE                           FUEL 018
C                                                                       FUEL 019
      CFS=PERF(3,IENGN)*PERF(1,IENGN)**0.25                             FUEL 020
      CA=TDRAG(1)/DISP                                                  FUEL 021
      CD=1.0+ (DELH(1,8) +DELH(1,7))*2.0*G/(VJ(1)*VJ(1))                FUEL 022
      WT(1)=0.0                                                         FUEL 023
      DIS(1)=DISP                                                       FUEL 024
      N=21                                                              FUEL 025
      XN=20.                                                            FUEL 026
      TI=RANGE/(VO(1)*XN)*1.689                                         FUEL 027
      IJK=0                                                             FUEL 028
      XJ=0.75                                                           FUEL 029
      DO1 I=2,N                                                         FUEL 030
      DIS(I)=DIS(I-1)-WT(I-1)                                           FUEL 031
      VJJ(I)=VO(1)/2.0+SQRT(VO(1)**2/4.0+DIS(I)*CA/(RHOW*AJET))         FUEL 032
      H=CD*VJJ(I)*VJJ(I)/(2.*G)-VO(1)*VO(1)/(2.*G)+HE                   FUEL 033
```

```
      SHPP=(RHOW*G*AJET*VJJ(I)*H)/(550.*ETAP(1,NSTG)*ETAP(7,NSTG))      FUEL 034
      SHNG=SHPP/FLOAT(NGT)                                              FUEL 035
      IF(SHNG.GT.0.7*PERF(1,IENGN).OR.IJK.EQ.1)  GO TO 4                FUEL 036
      CFS=CFS*SQRT(SHNG)                                                FUEL 037
      IJK=1                                                             FUEL 038
      XJ=0.25                                                           FUEL 039
    4 WT(I)=CFS*TI*SHPP**XJ*FLOAT(NGT)**(1.-XJ)                         FUEL 040
    1 CONTINUE                                                          FUEL 041
      DO2 M=2,N                                                         FUEL 042
    2 WT(M)=WT(M)+WT(M-1)                                               FUEL 043
      WE=WT(N)                                                          FUEL 044
      RETURN                                                            FUEL 045
   10 DO 11 I=ISTRT,NUMB
      CFS=PERF(3,IENGN)*PERF(1,IENGN)**.25
      ENN=.75
      IF(SHP(I,NSTG).LT.(0.7*PERF(1,IENGN)))CFS=CFS*SQRT(SHP(I,NSTG))
      IF(SHP(I,NSTG).LT.(0.7*PERF(1,IENGN)))ENN=.25
      FRATE(I)=CFS*FLOAT(NGT)*SHP(I,NSTG)**ENN
      WE=WGTS(2,11)
   11 CONTINUE
      RETURN
      END
```

```
 SUBROUTINE NACEL                                                     NACL0001
 COMMON /WARN/CAV(5,6)
 COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                      NACL0003
 COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP                  NACL0004
 COMMON /CONST/PI,G,RHOD                                              NACL0005
 COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ              NACL0006
 COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                      NACL0007
 COMMON /INDEX/IFVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICCMP,NPUMP,NGT,
AIGEAR
 COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),        NACL0009
1 TRIM(5)                                                             NACL0010
 COMMON /CDRAG/CSTRT(5),CPOD(5),CSPRY(5)                              NACL0011
 COMMON /TOLER/DELTA                                                  NACL0012
 COMMON /NACLL/DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN,AAX(5)
 COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)              NACL0014
 DIMENSION TLIP(5)
 DIMENSION NL(2),ML(2),KL(2),JL(2),IL(2)                              NACL0015
 DIMENSION AA(30),AB(30),AC(30),AD(30),AE(30),AF(30),AG(30),AH(30) NACL0016
 DIMENSION BA(30),BB(30),BC(30),BD(30),BE(30),BF(30),BG(30),BH(30) NACL0017
 DIMENSION ALFAT(4),VRT(6), XDT(10),CPINT(6,10,4),CPEXT(6,10,4),      NACL0018
1PRLT(6),SIGI(5),PTO(5),XDTT(4),CDUMX(10),  CDUMY(10),  AT(2),CD(5)NACL0019
2,DIDMT(10),VRTT(4),DLIP(5),QO(5),VELP(5),VRTEX(4),VRMAX(5)           NACL0020
 EQUIVALENCE (CPINT(1,1,1),AA(1)),(CPINT(1,6,1),AB(1)),(CPINT(1,1,2NACL0021
1),AC(1)),(CPINT(1,6,2),AD(1)),(CPINT(1,1,3),AE(1)),(CPINT(1,6,3), NACL0022
2AF(1)),(CPINT(1,1,4),AG(1)),(CPINT(1,6,4),AH(1)),(CPEXT(1,1,1),BA(NACL0023
31)),(CPEXT(1,6,1),BB(1)),(CPEXT(1,1,2),BC(1)),(CPEXT(1,6,2),BD(1))NACL0024
4,(CPEXT(1,1,3),BE(1)),(CPEXT(1,6,3),BF(1)),(CPEXT(1,1,4),BG(1)),  NACL0025
5(CPEXT(1,6,4),BH(1))                                                 NACL0026
 EQUIVALENCE (AT(1),ALFAT(1)),(DRAT,DIDM)                             NACL0027
 DATA NL,ML,KL,JL/6, 2,2,2,10,3,6,3/,IL/4,2/                          NACL0028
 DATA PRLT/0.973,0.969,0.962,0.945,0.928,0.909/                       NACL0029
 DATA ALFAT/0.0,2.0,4.0,6.0/,                                         NACL0030
1 XDT/0.25,0.50,0.75,1.0,1.25,1.50,1.75,2.0,2.25,2.5/,DIDMT/0.810,  NACL0031
2 0.695,0.627,0.577,0.533,0.490,0.439,0.365,0.260,0.090/             NACL0032
3, VRT/.7,.8,.9,1.05,1.15,1.25/                                       NACL0033
 DATA AA/                                                             NACL0034
```

```
A  0.170  , -0.150  , -0.540  , -1.300  , -1.980  , -2.770  ,       NACL0035
B  0.267  ,  0.010  , -0.300  , -0.860  , -1.330  , -1.925  ,       NACL0036
C  0.335  ,  0.125  , -0.145  , -0.605  , -0.965  , -1.415  ,       NACL0037
D  0.378  ,  0.175  , -0.055  , -0.470  , -0.775  , -1.120  ,       NACL0038
E  0.403  ,  0.212  , -0.005  , -0.383  , -0.665  , -0.975  /       NACL0039
 DATA AB/                                                           NACL0040
A  0.413  ,  0.233  ,  0.026  , -0.333  , -0.510  , -0.887  ,       NACL0041
B  0.417  ,  0.245  ,  0.053  , -0.302  , -0.506  , -0.832  ,       NACL0042
C  0.419  ,  0.254  ,  0.071  , -0.278  , -0.502  , -0.790  ,       NACL0043
D  0.420  ,  0.262  ,  0.082  , -0.259  , -0.499  , -0.752  ,       NACL0044
E  0.421  ,  0.271  ,  0.090  , -0.241  , -0.480  , -0.720  /       NACL0045
 DATA AC/                                                           NACL0046
A  0.000  , -0.360  , -0.800  , -1.570  , -2.430  , -3.900  ,       NACL0047
B  0.157  , -0.125  , -0.475  , -1.118  , -1.680  , -2.750  ,       NACL0048
C  0.260  ,  0.018  , -0.258  , -0.788  , -1.075  , -1.670  ,       NACL0049
D  0.328  ,  0.102  , -0.130  , -0.583  , -0.930  , -1.250  ,       NACL0050
E  0.365  ,  0.160  , -0.060  , -0.464  , -0.770  , -1.020  /       NACL0051
 DATA AD/                                                           NACL0052
A  0.386  ,  0.196  , -0.018  , -0.385  , -0.664  , -0.902  ,       NACL0053
B  0.398  ,  0.220  ,  0.011  , -0.330  , -0.595  , -0.836  ,       NACL0054
C  0.407  ,  0.238  ,  0.034  , -0.287  , -0.545  , -0.780  ,       NACL0055
D  0.414  ,  0.252  ,  0.055  , -0.258  , -0.507  , -0.766  ,       NACL0056
E  0.417  ,  0.263  ,  0.071  , -0.222  , -0.482  , -0.742  /       NACL0057
 DATA AE/                                                           NACL0058
A -0.215  , -0.590  , -1.140  , -2.150  , -3.150  , -4.450  ,       NACL0059
B  0.020  , -0.295  , -0.700  , -1.465  , -2.185  , -3.240  ,       NACL0060
C  0.160  , -0.105  , -0.408  , -0.980  , -1.450  , -2.000  ,       NACL0061
D  0.255  ,  0.010  , -0.255  , -0.710  , -1.070  , -1.455  ,       NACL0062
E  0.310  ,  0.088  , -0.145  , -0.554  , -0.860  , -1.180  /       NACL0063
 DATA AF/                                                           NACL0064
A  0.345  ,  0.152  , -0.075  , -0.450  , -0.725  , -1.024  ,       NACL0065
B  0.367  ,  0.200  , -0.030  , -0.383  , -0.643  , -0.930  ,       NACL0066
C  0.386  ,  0.225  ,  0.012  , -0.328  , -0.589  , -0.880  ,       NACL0067
D  0.401  ,  0.243  ,  0.048  , -0.280  , -0.541  , -0.850  ,       NACL0068
E  0.412  ,  0.258  ,  0.060  , -0.245  , -0.509  , -0.820  /       NACL0069
 DATA AG/                                                           NACL0070
```

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     A -0.550  , -0.950  , -1.600  , -2.940  , -3.500  , -5.200  ,         NACL0071
     B -0.250  , -0.570  , -1.020  , -1.900  , -2.650  , -3.920  ,         NACL0072
     C  0.000  , -0.275  , -0.600  , -1.230  , -1.770  , -2.385  ,         NACL0073
     D  0.150  , -0.045  , -0.340  , -0.950  , -1.365  , -1.960  ,         NACL0074
     E  0.255  ,  0.020  , -0.200  , -0.800  , -1.215  , -1.800  /         NACL0075
      DATA AH/                                                             NACL0076
     A  0.315  ,  0.120  , -0.110  , -0.685  , -1.130  , -1.715  ,         NACL0077
     B  0.355  ,  0.173  , -0.050  , -0.614  , -1.087  , -1.665  ,         NACL0078
     C  0.375  ,  0.195  ,  0.000  , -0.575  , -1.060  , -1.640  ,         NACL0079
     D  0.392  ,  0.225  ,  0.032  , -0.545  , -1.035  , -1.625  ,         NACL0080
     E  0.405  ,  0.248  ,  0.060  , -0.520  , -1.017  , -1.617  /         NACL0081
      DATA BA/                                                             NACL0082
     A -0.485  , -0.460  , -0.450  , -0.410  , -0.400  , -0.385  ,         NACL0083
     B -0.335  , -0.330  , -0.315  , -0.300  , -0.295  , -0.280  ,         NACL0084
     C -0.240  , -0.239  , -0.230  , -0.225  , -0.220  , -0.215  ,         NACL0085
     D -0.175  , -0.135  , -0.170  , -0.170  , -0.165  , -0.164  ,         NACL0086
     E -0.140  , -0.145  , -0.135  , -0.140  , -0.135  , -0.135  /         NACL0087
      DATA BB/                                                             NACL0088
     A -0.115  , -0.120  , -0.110  , -0.115  , -0.110  , -0.115  ,         NACL0089
     B -0.100  , -0.105  , -0.100  , -0.100  , -0.100  , -0.100  ,         NACL0090
     C -0.093  , -0.095  , -0.095  , -0.095  , -0.092  , -0.095  ,         NACL0091
     D -0.090  , -0.090  , -0.090  , -0.090  , -0.090  , -0.090  ,         NACL0092
     E -0.088  , -0.088  , -0.088  , -0.088  , -0.088  , -0.085  /         NACL0093
      DATA BC/                                                             NACL0094
     A -0.540  , -0.500  , -0.490  , -0.460  , -0.410  , -0.435  ,         NACL0095
     B -0.365  , -0.350  , -0.335  , -0.320  , -0.305  , -0.305  ,         NACL0096
     C -0.270  , -0.265  , -0.245  , -0.235  , -0.230  , -0.230  ,         NACL0097
     D -0.205  , -0.205  , -0.185  , -0.175  , -0.175  , -0.180  ,         NACL0098
     E -0.165  , -0.160  , -0.145  , -0.140  , -0.140  , -0.145  /         NACL0099
      DATA BD/                                                             NACL0100
     A -0.140  , -0.130  , -0.120  , -0.115  , -0.115  , -0.120  ,         NACL0101
     B -0.125  , -0.110  , -0.105  , -0.100  , -0.100  , -0.105  ,         NACL0102
     C -0.115  , -0.095  , -0.095  , -0.095  , -0.092  , -0.095  ,         NACL0103
     D -0.110  , -0.090  , -0.090  , -0.090  , -0.090  , -0.090  ,         NACL0104
     E -0.105  , -0.085  , -0.085  , -0.085  , -0.088  , -0.085  /         NACL0105
      DATA BE/                                                             NACL0106
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     A -0.595   , -0.535  , -0.535  , -0.460  , -0.445  , -0.445   ,     NACL0107
     B -0.420   , -0.390  , -0.370  , -0.350  , -0.335  , -0.330   ,     NACL0108
     C -0.330   , -0.310  , -0.275  , -0.260  , -0.260  , -0.260   ,     NACL0109
     D -0.275   , -0.265  , -0.215  , -0.205  , -0.205  , -0.195   ,     NACL0110
     E -0.250   , -0.230  , -0.175  , -0.165  , -0.165  , -0.160   /     NACL0111
      DATA BF/                                                            NACL0112
     A -0.235   , -0.205  , -0.145  , -0.145  , -0.140  , -0.138   ,     NACL0113
     B -0.235   , -0.135  , -0.135  , -0.130  , -0.125  , -0.125   ,     NACL0114
     C -0.240   , -0.170  , -0.125  , -0.120  , -0.118  , -0.118   ,     NACL0115
     D -0.250   , -0.155  , -0.120  , -0.115  , -0.115  , -0.113   ,     NACL0116
     E -0.265   , -0.145  , -0.118  , -0.112  , -0.114  , -0.110   /     NACL0117
      DATA BG/                                                            NACL0118
     A -0.670   , -0.610  , -0.570  , -0.525  , -0.475  , -0.480   ,     NACL0119
     B -0.485   , -0.460  , -0.415  , -0.380  , -0.365  , -0.360   ,     NACL0120
     C -0.395   , -0.373  , -0.335  , -0.293  , -0.285  , -0.280   ,     NACL0121
     D -0.348   , -0.322  , -0.285  , -0.235  , -0.232  , -0.225   ,     NACL0122
     E -0.331   , -0.300  , -0.255  , -0.200  , -0.195  , -0.190   /     NACL0123
      DATA BH/                                                            NACL0124
     A -0.337   , -0.295  , -0.238  , -0.176  , -0.171  , -0.168   ,     NACL0125
     B -0.360   , -0.300  , -0.231  , -0.163  , -0.157  , -0.154   ,     NACL0126
     C -0.400   , -0.310  , -0.230  , -0.157  , -0.150  , -0.145   ,     NACL0127
     D -0.447   , -0.323  , -0.229  , -0.155  , -0.146  , -0.139   ,     NACL0128
     E -0.499   , -0.336  , -0.230  , -0.153  , -0.144  , -0.135   /     NACL0129
      FRICT(RE)=(.36859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)           NACL0130
C                                                                         NACL0131
C       ZK   IS THE DECIMAL PART OF THE ANNULUS OCCUPIED BY THE           NACL0132
C       AUXILIARY INLET THAT IS ACTUALLY OPENING.  THE REMAINDER IS       NACL0133
C       STRUCTURE.                                                        NACL0134
C                                                                         NACL0135
      ZK=.8                                                               NACL0136
      SPO=(HS+HA)*RHOW*G                                                  NACL0137
      PVP=PV*RHOW*G                                                       NACL0138
C                                                                         NACL0140
C       SIGTV  IS THE INCIPIENT CAVITATION NO. ON THE ELBOW TURNING       NACL0141
C       VANES REFERENCED TO DIFFUSER EXIT PRESSURE AND VELOCITY.          NACL0142
C                                                                         NACL0143
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      SIGTV=0.4                                                         NACL0144
      JNUMB=2                                                           NACL0145
      IF(ISTRT.EQ.3)JNUMB=NUMB                                          NACL0146
      DO 10 I=ISTRT,JNUMB                                               NACL0147
      VELR(I)=VI(I)/VO(I)
      QO(I)=.5*RHOW*VO(I)*VO(I)                                         NACL0148
C                                                                       NACL0149
C      SIGI(I) IS THE INCIPIENT CAVITATION NO. REFERENCED TO FREE STREAMNACL0150
C      CONDITIONS.                                                      NACL0151
C                                                                       NACL0152
      SIGI(I)=(SPO-PVP)/QO(I)                                           NACL0153
      PTO(I)=SPO+QO(I)                                                  NACL0154
      IF(ISTRT.EQ.1) GO TO 10
      IF(TRIM(I).GT.3) TRIM(I)=3.
   10 CONTINUE                                                          NACL0155
      IF(TRIM(1).GT.3.)TRIM(1)=3.                                       NACL0156
C                                                                       NACL0158
C      INTERPOLATE IN THE DATA TABLE TO FIND THE INLET WITH THE DESIRED NACL0159
C      PRESSURE COEFFICIENT.                                            NACL0160
C                                                                       NACL0161
      KNUMB=NUMB
      IF(ISTRT.EQ.1) KNUMB=ISTRT
      DO 211 IE=ISTRT,KNUMB
      CPEX=-SIGI(IE)
      DO 610 I=1,2                                                      NACL0162
      DO 609 K=1,10                                                     NACL0163
      DO 608 J=1,6                                                      NACL0164
      CDUMX(J)=CPEXT(J,K,I)                                             NACL0165
  608 CONTINUE                                                          NACL0166
      CDUMY(K)=TABLE(VRT,CDUMX,VELR(1),NL)                              NACL0167
  609 CONTINUE                                                          NACL0168
      XDTT(I)=TABLE(CDUMY,XDT,CPEX,KL)                                  NACL0169
  610 CONTINUE                                                          NACL0170
      ML(1)=2                                                           NACL0171
      XD=TABLE(AT,XDTT,TRIM(1),ML)                                      NACL0172
      DIDMX=TABLE(XDT,DIDMT,XD,KL)                                      NACL0173
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      IF(DIDMX.LT.DIDM) CAV(IE,1)=1.
      IF(ISTRT.EQ.3) GO TO 201
      WGTS(1,1)=1.E9                                                    NACL0174
C                                                                       NACL0175
C      IF THE TRIAL NACELLE HAS LESS FRONTAL AREA THAN THE MINIMUM      NACL0176
C      REQUIRED TO AVOID CAVITATION, REJECT THE TRIAL VALUE.  IF NON-   NACL0177
C      CAVITATING, CALCULATE INLET DIMENSIONS.                          NACL0178
C                                                                       NACL0179
      IF(DIDMX.LT.DIDM*(1.+DELTA)) DIDM=DIDMX                           NACL0180
      QI=.5*Q(1)                                                        NACL0181
      AI=QI/VI(1)                                                       NACL0182
      DI=SQRT(AI)*1.12838                                               NACL0183
   11 CONTINUE                                                          NACL0184
      DM=DI/DIDM                                                        NACL0185
      XD=TABLE(DIDMT,XDT,DIDM,KL)                                       NACL0186
      ELEXT=DM*XD                                                       NACL0187
C     ASSUMING THE AUX. INLETS ALLOW FLOW TO ENTER BEFORE THE DIFFUSER, NACL0188
C     CALCULATE LOSSES AND TOTAL PRESSURE OF THE COMBINED FLOW.         NACL0189
  201 IF(ISTRT.EQ.1) CPIN=-SIGI(2)
C                                                                       NACL0191
C      INTERPOLATE IN THE DATA TABLE TO DETERMINE THE MAXIMIM VELOCITY  NACL0192
C      RATIOS AT CRUISE AND TAKE-OFF.                                   NACL0193
C                                                                       NACL0194
      DO 710 I=1,4                                                      NACL0195
      DO 709 K=1,6                                                      NACL0196
      DO 708 J=1,10                                                     NACL0197
      CDUMX(J)=CPINT(K,J,I)                                             NACL0198
  708 CONTINUE                                                          NACL0199
      CDUMY(K)=TABLE(XDT,CDUMX,XD,KL)                                   NACL0200
  709 CONTINUE                                                          NACL0201
      IF(ISTRT.EQ.1) VRTT(I)=TABLE(CDUMY,VRT,CPIN,IL)
      VRTEX(I)=TABLE(CDUMY,VRT,CPEX,IL)                                 NACL0203
  710 CONTINUE                                                          NACL0204
      ML(1)=4                                                           NACL0205
      VRMAX(IE)=TABLE(ALFAT,VRTEX,TRIM(IE),ML)
      IF(ISTRT.EQ.1) VRMAX(2)=TABLE(ALFAT,VRTT,TRIM(2),ML)
```

```
C                                                                       NACL0208
C     CHECK FOR LIP CAVITATION. IF CAVITATING, RETURN                   NACL0209
C                                                                       NACL0210
      IF(VELR(IE).GT.VRMAX(IE).AND.DELTA.GT.1.E-9) RETURN
      CAV(IE,2)=0.
      IF(VELR(IE).GT.VRMAX(IE)) CAV(IE,2)=2.
  211 CONTINUE
      IF(ISTRT.EQ.3) GO TO 203
C      DETERMINE MAX. FLOW RATE AT TAKE-OFF AND COMPARE WITH REQUIRED   NACL0213
C      FLOW RATE.  AN AUXILIARY INLET MUST BE SIZED TO ACCEPT ANY EXCESSNACL0214
C      REQUIRED FLOW.                                                   NACL0215
C                                                                       NACL0216
      QIN=AI*VRMAX(2)*VO(2)                                             NACL0217
      QC=0.5*Q(2)                                                       NACL0218
      QAUX=QC-QIN                                                       NACL0219
      IF(QAUX.LE.0.)QAUX=0.                                             NACL0220
      QIN=QC-QAUX                                                       NACL0221
C     CALCULATE STATIC PRESSURE IMMEDIATELY AFT. OF THE LIP.            NACL0222
      VI2=QIN/AI                                                        NACL0223
      VR=VI2/VO(2)                                                      NACL0224
      PRL2=TABLE(VRT,PRLT,VR,JL)                                        NACL0225
      PTI=PRL2*QO(2)+SPC                                                NACL0226
      SPI=PTI-0.5*RHOW*VI2*VI2                                          NACL0227
C     CALCULATE COMBINED FLOW PRESSURES AND AUX. INLET AREA.            NACL0228
      AIAUX=0.                                                          NACL0229
      VIAUX=0.                                                          NACL0230
      PTAUX=0.                                                          NACL0231
      IF(QAUX.EQ.0.)GO TO 12                                            NACL0232
      PRAUX=0.80                                                        NACL0233
      PTAUX=PRAUX*QO(2)+SPC                                             NACL0234
      DYP=PTAUX-SPI                                                     NACL0235
      VIAUX=SQRT(2.*DYP/RHOW)                                           NACL0236
      AIAUX=QAUX/VIAUX                                                  NACL0237
   12 CONTINUE                                                          NACL0238
C                                                                       NACL0239
C       THE TOTAL PRESSURE OF THE COMBINED FLOW IS CALCULATED AS THE    NACL0240
```

```
C      MASS WEIGHTED AVERAGE OF THE COMBINING FLOWS.                    NACL0241
C                                                                       NACL0242
      PC=(PTI*QIN+PTAUX*QAUX)/QC                                        NACL0243
      VI(2)=QC/AI                                                       NACL0244
      DLIP(2)=1.-(PC-SPO)/QO(2)                                         NACL0245
      QDIF=QC                                                           NACL0246
C                                                                       NACL0247
C      CALCULATE THE INTERNAL LENGTHS TO THE DIFFUSER ENTRY.            NACL0248
C                                                                       NACL0249
      ELENT=ELEXT/9.                                                    NACL0250
      PHI=ATAN(.5*(DM-DI)/ELEXT)                                        NACL0251
      PHS=SIN(PHI)                                                      NACL0252
      X=.5*(SQRT(DI**2+1.27324*AIAUX*PHS/ZK)-DI)/PHS                    NACL0253
      ELAUX=X/COS(PHI)                                                  NACL0254
C     SIZE THE DIFFUSER                                                 NACL0255
      D2=0.9*DM                                                         NACL0256
      D1=DI                                                             NACL0257
      IF(D2.LT.D1)D2=D1                                                 NACL0258
      ELMAX=9.22339*(D2-D1)                                             NACL0259
      ELMIN=2.836075*(D2-D1)                                            NACL0260
C     DECIDE WHICH CONDITION GOVERNS THE DIFFUSER.                      NACL0261
      IF(QI.GT.QC)GO TO 13                                              NACL0262
      II=2                                                              NACL0263
      GO TO 14                                                          NACL0264
   13 CONTINUE                                                          NACL0265
      II=1                                                              NACL0266
      QDIF=QI                                                           NACL0267
   14 CONTINUE                                                          NACL0268
      EL=0.45*(ELMAX+ELMIN)                                             NACL0269
      ELD=ELENT+EL+3.54491*D2+ELAUX                                     NACL0270
      ELL=5.5*DM                                                        NACL0271
      ELN=ELD                                                           NACL0272
      IF(ELL.GE.ELD)ELN=ELL                                             NACL0273
      DDM=0.5*(D2+D1)                                                   NACL0274
      XKT=(1.-(D1/D2)**2)**2                                            NACL0275
      ANGL=ATAN((D2-D1)/(2.*EL    ))*57.2958                            NACL0276
```

```
      CDIF=3.19E-3*ANGL*ANGL+8.452E-4*ANGL                              NACL0277
C                                                                       NACL0278
C      ELDIF  IS THE DIFFUSER LENGTH REQUIRING THE LEAST TOTAL POWER    NACL0279
C      FOR THE DESIRED  DIFFUSION RATIO.                                NACL0280
C                                                                       NACL0281
      ELDIF=EL                                                          NACL0282
C                                                                       NACL0283
C      CALCULATE THE LIP LOSSES FOR EACH SITUATION.                     NACL0284
C                                                                       NACL0285
      DLIP(1)=1.-TABLE(VRT,PRLT,VELR(1),JL)                             NACL0286
  203 IF(NUMB.LT.3) GO TO 113
      DO 15 J=3,NUMB                                                    NACL0288
      VI(J)=.5*Q(J)/AI                                                  NACL0289
      VELR(J)=VI(J)/VO(J)                                               NACL0290
      DLIP(J)=1.-TABLE(VRT,PRLT,VELR(J),JL)                             NACL0291
      IF(CAV(J,2).EQ.0.) GO TO 15
      AAX(J)=0.
      VIAUX=0.
      PTAUX=0.
      QIN=AI*VRMAX(J)*VO(J)
      QC=0.5*Q(J)
      QAUX=QC-QIN
      IF(QAUX.LE.0.) GO TO 15
      VIJ=QIN/AI
      VR=VIJ/VO(J)
      PRLJ=TABLE(VRT,PRLT,VR,JL)
      PTI=PRLJ*QC(J)+SPC
      SPI=PTI-0.5*RHOW*VIJ**2
      PRAUX=0.8
      PTAUX=PRAUX*QO(J)+SPC
      DYP=PTAUX-SPI
      VIAUX=SQRT(2.*DYP/RHOW)
      AAX(J)=QAUX/VIAUX
      PC=(PTI*QIN+PTAUX*QAUX)/QC
      TLIP(J)=1.-(PC-SPC)/QC(J)
      IF(AAX(J).GT.AIAUX) CAV(J,2)=1.
```

```
      IF(CAV(J,2).NE.1.) DLIP(J)=TLIP(J)
   15 CONTINUE                                                          NACL0292
  113 JNUMB=2                                                           NACL0293
      IF(ISTRT.NE.3) GO TO 251
      JNUMB=NUMB
      D1=DI
      D2=SQRT(AREA(1)/(PI*0.5))
      DDM=0.5*(D2+D1)
      XKT=(1.-(D1/D2)**2)**2
      ANGL=ATAN((D2-D1)/(2.*ELDIF))*57.2958
      CDIF=3.19E-3*ANGL*ANGL+8.452E-4*ANGL
  251 CONTINUE
      DO 17 I=ISTRT,JNUMB                                               NACL0295
C                                                                       NACL0297
C      CALCULATE THE DIFFUSER AND PIPE LOSSES FOR EACH SITUATION AND    NACL0298
C      ADD TO THE LIP LOSSES.                                           NACL0299
C                                                                       NACL0300
      REND=D1*VI(I)/GNU                                                 NACL0301
      DDIF=(CDIF*XKT+FRICT(REND)*ELDIF/DDM)*0.5*RHOW*VI(I)*VI(I)        NACL0302
      PLOSS=DLIP(I)*QO(I)+DDIF+FRICT(REND)*ELAUX/DI*.5*RHOW*VI(I)*VI(I)
      IF(I.EQ.2) PLOSS=DLIP(2)*QO(2)+DDIF                               NACL0304
      IF(CAV(I,2).EQ.2.) PLOSS=DLIP(I)*QO(I)+DDIF
      VAOUT=Q(I)*0.63662/(D2*D2)                                        NACL0305
      SQUAR=SIGI(I)+1.-PLOSS/QO(I)                                      NACL0306
C                                                                       NACL0307
C      DETERMINE THE CRITICAL LOCAL VELOCITY AT THE DIFFUSER EXIT AT    NACL0308
C      WHICH CAVITATION ON THE TURNING VANES OCCURS.                    NACL0309
C                                                                       NACL0310
      VCRIT=SQRT(SQUAR)*VO(I)/SQRT(1.+SIGTV)                            NACL0311
C                                                                       NACL0312
C      ESTIMATE THE MAXIMUM LOCAL VELOCITY AT THE DIFFUSER EXIT.        NACL0313
C                                                                       NACL0314
      VMAX=1.50*VAOUT                                                   NACL0315
C                                                                       NACL0316
C      IF CAVITATION OCCURS, REJECT ON DESIGN, INDICATE ON EVALUATION.  NACL0317
C                                                                       NACL0318
```

```
      IF(VMAX.GT.VCRIT)CAV(I,3)=1.
      IF(VMAX.GT.VCRIT.AND.ISTRT.EQ.1.AND.DELTA.GT.1.E-9) RETURN          NACL0320
C                                                                         NACL0321
C     AT THIS POINT THE DIFFUSER HAS BEEN SIZED TO AVOID CAVITATION AT    NACL0322
C      BOTH TAKE/OFF AND CRUISE. INTERNAL FLOW LOSSES ARE DETERMINED      NACL0323
C                                                                         NACL0324
      DELH(I,1)=PLOSS/(RHOW*G)                                            NACL0325
      RENL=ELN*VC(I)/GNU                                                  NACL0326
C                                                                         NACL0327
C      CALCULATE THE DRAG COEFFICIENTS.                                   NACL0328
C                                                                         NACL0329
      CD(I)=CFS(RENL)*(1.+1.5*(DM/ELN)**(3/2)+7.*(DM/ELN)**3)             NACL0330
C                                                                         NACL0331
C     CALCULATE WETTED SURFACE AND DRAG.                                  NACL0332
C                                                                         NACL0333
      EM=SQRT(1.+4.*((2.*ELEXT)/DM)**2)                                   NACL0334
      AEXN=1.0472*DM*DM*(EM+1./(EM+1.))+PI*DM*(ELN-2.*ELEXT)              NACL0335
      CPOD(I)=2.*QC(I)*AEXN*CD(I)                                         NACL0336
   17 CONTINUE                                                            NACL0337
      AREA(1)=PI*D2*D2*0.5                                                NACL0338
      CGS(1,1)=HS+HE-HCL                                                  NACL0339
      CGS(2,1)=XLS+.5*(ELN-3.54491*D2)                                    NACL0340
      IF(THATA(1).GE.90.)GO TO 18                                         NACL0341
      CGS(2,1)=CGS(2,1)+CGS(1,1)/TAN(THATA(1)*.0174533)                   NACL0342
   18 CGS(3,1)=0.                                                         NACL0343
      CGS(4,1)=0.                                                         NACL0344
      WGTS(1,1)=.11*DM*AEXN*(.5*RHOD-RHOW)+15.07*AREA(1)*(ELENT+ELAUX+    NACL0345
     A EL)                                                                NACL0346
      RETURN                                                              NACL0347
      END                                                                 NACL0348
```

```
      SUBROUTINE PTTRN(PSI,SPSI,N,FCT,DEL,DLMIN)                        PTTR0001
C     ..................................................................PTTR0002
C        SUBROUTINE PTTRN                                               PTTR0003
C        PURPOSE                                                        PTTR0004
C           TO FIND THE MINIMUM OF A FUNCTION BY DIRECT SEARCH          PTTR0005
C                                                                       PTTR0006
C        USAGE                                                          PTTR0007
C           CALL PTTRN(PSI,SPSI,N,FCT,DEL,DELMIN)                       PTTR0008
C                                                                       PTTR0009
C        DESCRIPTION OF PARAMETERS                                      PTTR0010
C           PSI   - A LINEAR ARRAY OF LENGTH N OF COORDINATES OF THE    PTTR0011
C                   ORIGIN OF SEARCH, INPUT                             PTTR0012
C           SPSI  - THE MINIMUM VALUE OF THE FUNCTION, OUTPUT           PTTR0013
C           N     - THE NUMBER OF PARAMETERS (COORDINATES) OF THE       PTTR0014
C                   FUNCTION, INPUT                                     PTTR0015
C           FCT   - THE FUNCTION SUBPROGRAM CONTAINING THE FUNCTION TO  PTTR0016
C                   BE MINIMIZED                                        PTTR0017
C           DEL   - A LINEAR ARRAY OF LENGTH N CONTAINING THE INITIAL   PTTR0018
C                   STEP SIZE TO BE USED, INPUT                         PTTR0019
C           DLMIN - A LINEAR ARRAY OF LENGTH N CONTAINING THE MINIMUM   PTTR0020
C                   STEP SIZES TO BE USED, INPUT                        PTTR0021
C                                                                       PTTR0022
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED                  PTTR0023
C           FCT                                                         PTTR0024
C                                                                       PTTR0025
C        REMARKS                                                        PTTR0026
C           THE CALLING PROGRAM MUST DECLARE THE FUNCTION SUBPROGRAM    PTTR0027
C           FCT IN AN EXTERNAL STATEMENT                                PTTR0028
C                                                                       PTTR0029
C           THIS SUBROUTINE IS A MODIFIED VERSION OF THAT SUGGESTED BY  PTTR0030
C           HOOKE AND JEEVES AND FOLLOWS THE NOTATION OF THAT PAPER     PTTR0031
C                                                                       PTTR0032
C        REFERENCES                                                     PTTR0033
C           1. HOOKE AND JEEVES, JACM,8(2),APR 61,PP 212-229            PTTR0034
C           2. ALGORITHM 178 AND SUBSEQUENT REMARKS, CACM               PTTR0035
C                                                                       PTTR0036
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C     ..................................................................PTTR0037
C                                                                       PTTR0038
      DIMENSION PSI(1),THETA(9),PHI(9),DEL(1),DLMIN(1),DIR(9),SAVE(9)   PTTR0039
      DATA RHO/.5/                                                      PTTR0040
C                                                                       PTTR0041
C     EVALUATE THE FUNCTION AT THE INITIAL POINT                        PTTR0042
C                                                                       PTTR0043
      SPSI=FCT(PSI)                                                     PTTR0044
C                                                                       PTTR0045
C     SET THE BASEPOINT                                                 PTTR0046
C                                                                       PTTR0047
    1 S=SPSI                                                            PTTR0048
      DO 10 I=1,N                                                       PTTR0049
   10 PHI(I)=PSI(I)                                                     PTTR0050
C                                                                       PTTR0051
C     ICALL=1 INDICATES THE BASEPOINT HAS JUST BEEN UPDATED             PTTR0052
C                                                                       PTTR0053
      ICALL=1                                                           PTTR0054
C                                                                       PTTR0055
C     MAKE EXPLORATORY MOVES FROM THE BASEPOINT                         PTTR0056
C                                                                       PTTR0057
      GO TO 99                                                          PTTR0058
C                                                                       PTTR0059
C     STORE PREVIOUS POINTS                                             PTTR0060
C                                                                       PTTR0061
    2 SPSI=S                                                            PTTR0062
      DO 11 I=1,N                                                       PTTR0063
      THETA(I)=PSI(I)                                                   PTTR0064
      PSI(I)=PHI(I)                                                     PTTR0065
C                                                                       PTTR0066
C     MAKE PATTERN MOVE (I.E. SIMULTANEOUSLY MOVE THE DISTANCE FROM THE PTTR0067
C     BASEPOINT TO THE PRESENT POINT IN EACH COORDINATE)                PTTR0068
C                                                                       PTTR0069
   11 PHI(I)=2.*PHI(I)-THETA(I)                                         PTTR0070
      SPHI=FCT(PHI)                                                     PTTR0071
      S=SPHI                                                            PTTR0072
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C                                                                       PTTR0073
C     ICALL=2 INDICATES PATTERN MOVE JUST MADE                          PTTR0074
C                                                                       PTTR0075
      ICALL=2                                                           PTTR0076
C                                                                       PTTR0077
C     MAKE EXPLORATORY MOVES FROM RESULTING POINT OF PATTERN MOVE       PTTR0078
C                                                                       PTTR0079
      GO TO 99                                                          PTTR0080
C                                                                       PTTR0081
C     DECREMENT STEP SIZE BY A FACTOR OF RHO                            PTTR0082
C                                                                       PTTR0083
    3 NUMB=0                                                            PTTR0084
      DO 31 I=1,N                                                       PTTR0085
      IF(DEL(I).GT.DLMIN(I)) GO TO 31                                   PTTR0086
      NUMB=NUMB+1                                                       PTTR0087
   31 DEL(I)=RHO*DEL(I)                                                 PTTR0088
C                                                                       PTTR0089
C     IF ALL STEP SIZES ARE LESS THAN MINIMUM, RETURN TO CALLING PROGRAMPTTR0090
C     OTHERWISE, START OFF FROM BASEPOINT WITH SMALLER STEP             PTTR0091
C                                                                       PTTR0092
      IF(NUMB.EQ.N) RETURN                                              PTTR0093
      GO TO 1                                                           PTTR0094
C                                                                       PTTR0095
C     MAKE EXPLORATORY MOVES                                            PTTR0096
C                                                                       PTTR0097
   99 DO 95 K=1,N                                                       PTTR0098
      SAVE(K)=PHI(K)                                                    PTTR0099
      SIGN=DEL(K)                                                       PTTR0100
      PHI(K)=SAVE(K)+SIGN                                               PTTR0101
      SPHI=FCT(PHI)                                                     PTTR0102
      TSPHI=SPHI                                                        PTTR0103
      PHI(K)=SAVE(K)-SIGN                                               PTTR0104
      SPHI=FCT(PHI)                                                     PTTR0105
      IF(TSPHI.GT.SPHI) GO TO 98                                        PTTR0106
      SPHI=TSPHI                                                        PTTR0107
      PHI(K)=SAVE(K)+SIGN                                               PTTR0108
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   98 IF(SPHI.LT.S) GO TO 96                                                  PTTR0109
      PHI(K)=SAVE(K)                                                          PTTR0110
      GO TO 95                                                                PTTR0111
   96 S=SPHI                                                                  PTTR0112
   95 CONTINUE                                                                PTTR0113
C                                                                             PTTR0114
C     IF A EXPLORATORY MOVE IS SUCCESSFUL TRY A PATTERN MOVE IN THAT          PTTR0115
C     DIRECTION. IF ALL EXPLORATORY MOVES ARE UNSUCCESSFUL, DECREASE          PTTR0116
C     STEPSIZE AND RESET BASEPOINT                                            PTTR0117
C                                                                             PTTR0118
C     FOR NORMAL USE OF PTTRN, THE FOLLOWING STATEMENT SHOULD READ            PTTR0119
C     IF(S.GT.SPSI) GO TO (3,1),ICALL                                         PTTR0120
      IF(S.GT.SPSI-100.) GO TO (3,1),ICALL                                    PTTR0121
      GO TO 2                                                                 PTTR0122
      END                                                                     PTTR0123
```

```
 SUBROUTINE OUTPUT                                                 OUTPT000
 INTEGER ENGN(3,12)                                                OUTPT001
 LOGICAL IFUEL,IPUMP,TYGER
 COMMON /PINLP/ALPHA
 COMMON /WARN/CAV(5,6)
 COMMON /DRAG/IDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),     OUTPT003
1 TRIM(5)                                                          OUTPT004
 COMMON /CONST/ PI,G,RHOD                                          OUTPT005
 COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   OUTPT006
 COMMON /SHIP/ DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP              OUTPT007
 COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   OUTPT008
 COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           OUTPT009
 COMMON /STRTC/TC,T,C,T1,C1,CFM                                    OUTPT010
 COMMON /PUMM/DQ(5),D1S(5),D2S(5),XNS(5),SM(5,5),PLP(5),NSTG,SHI(5,
A5),XIM
 COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)      OUTPT013
 COMMON /HEAD/HPP(5),HSV(5),THOM(5),PHI(5,5),WF,WG,FRATE(5)
 COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           OUTPT015
 COMMON /NACLL/DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN,AAX(5) OUTPT016
 COMMON /INDEX/IFVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
AIGEAR
 COMMON IFUEL,IPUMP,TYGER
 DIMENSION VK(5)
 DIMENSION VJRAT(5),VIRAT(5),HEADL(5,15),CONDS(2,5),ELBWS(2,4),    OUTPT019
APC(5),LABEL(5,14),LOCAT(6,6)
 DATA CONDS/4H CRU,4HISE ,4H T/C,4H    ,4H EVA,4HL 1 ,4H EVA,4HL 2
A,4H EVA,4HL 3 /
 DATA ELBWS/4H STR,4HUT  ,4H HUL,4HL   ,4H PUM,4HP   ,4H DIV,4HERGEOUTPT022
A /                                                                OUTPT023
 DATA HEADL/75*0./                                                 OUTPT024
 DATA LABEL/4HNACE,4HLLE ,3*4H    ,4HSTRU,4HT EL,4HBOW ,2*4H    ,  OUTPT025
A 4HSTRU,4HT DI,4HFFUS,4HER  ,4H    ,4HHULL,4H ELB,4HOW  ,2*4H    ,OUTPT026
B 4HATHW,4HARTS,4HHIPS,4H LEN,4HGTH ,4HPUMP,4H ELB,4HOW  ,2*4H    ,OUTPT027
C 4HFORE,4H AND,4H AFT,4H LEN,4HGTH ,4HPUMP,4*4H    ,4HNOZZ,4HLE  ,OUTPT028
D 3*4H    ,4HREDU,4HCTIO,4HN GE,4HAR  ,4H    ,4HFUEL,4*4H    ,     OUTPT029
E 5*4H    ,4HJET ,4HLIFT,3*4H    ,4HTCTA,4HLS  ,3*4H    /          OUTPT030
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      DATA ENGN/4HTF35,2*4H    ,4HTF40,2*4H    ,4HPROT, 4HEUS ,4H1500,  OUTPT031
     A 4HPROT,4HEUS ,4H1000,  4HTYNE,4H 1A ,4H    ,4HTYNE,4H 1C ,4H    ,OUTPT032
     B 4HFT12,4HA   ,4H    ,4HLM15,4H00  ,4H    ,4HLM25,4H00  ,4H    ,  OUTPT033
     C 4HFT4A,4H-2C ,4H    ,4HFT4A,4H-12 ,4H    ,4HFT4C,4H-2  ,4H    /  OUTPT034
      DATA LOCAT/4H NAC,4HELLE,4H OUT,4HSIDE,4H    ,4H    ,4H NAC,4HELLE
     A,4H INL,4HET L,4HIP  ,4H    ,4H NAC,4HELLE,4H TUR,4HNING,4H VAN,4H
     RES  ,4H STR,4HUT D,4HUTSI,4HDE  ,4H    ,4H    ,4H PUM,4HP IN,4HLET
     C ,4H    ,4H    ,4H    /
      IPRNT=6                                                           OUTPT035
      WRITE(IPRNT,1)                                                    OUTPT036
    1 FORMAT(5X,49H **** WATERJET PROPULSION SYSTEM OUTPUT DATA ****,///OUTPT037
     A )                                                                OUTPT038
      DO 7 J=ISTRT,NUMB                                                 OUTPT039
      VJRAT(J)=VJ(J)/VC(J)                                              OUTPT040
      VIRAT(J)=VI(J)/VC(J)                                              OUTPT041
      HEADL(J,1)=DELH(J,1)                                              OUTPT042
      HEADL(J,2)=DELH(J,2)-DELH(J,1)                                    OUTPT043
      HEADL(J,3)=DELH(J,3)-HE+RC(2)*XK(2)-DELH(J,2)                     OUTPT044
      HEADL(J,4)=DELH(J,4)-RO(2)*XK(2)-DELH(J,3)                        OUTPT045
      SUM=0.                                                            OUTPT046
      DO 8 I=5,8                                                        OUTPT047
      HEADL(J,I)=DELH(J,I)-DELH(J,I-1)                                  OUTPT048
      IF(I.EQ.8) HEADL(J,8)=DELH(J,8)                                   OUTPT049
    8 SUM=SUM+HEADL(J,I)                                                OUTPT050
    7 HEADL(J,9) =SUM+HEADL(J,1)+HEADL(J,2)+HEADL(J,3)+HEADL(J,4)       OUTPT051
      DRATO=AREA(3)/AREA(2)                                             OUTPT052
      WRITE(IPRNT,3) AIN,DRATO,AJET                                     OUTPT053
    3 FORMAT(27H INLET AREA, TOTAL, FEET**2,F8.2,/,                     OUTPT054
     A 27H STRUT DIFFUSER AREA RATIO ,F8.2,/,                           OUTPT055
     B 25H JET AREA, TOTAL, FEET**2,2X,F8.2,//)                         OUTPT056
      IK=NPUMP+2-NPUMP/2                                                OUTPT057
      XNGT=NGT                                                          OUTPT058
      DO 30 K=ISTRT,NUMP                                                OUTPT059
   30 PC(K)=TDRAG(K)*VO(K)/(550.*SHP(K,NSTG)*XNGT)                      OUTPT060
      WRITE(IPRNT,12)                                                   OUTPT061
   12 FORMAT(24X,3HJET,15X,5HINLET)                                     OUTPT062
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      WRITE(IPRNT,11)                                                   OUTPT063
   11 FORMAT(10H FLOW RATE,5X,3HJET,4X,8HVELOCITY,2X,6H INLET,2X,       OUTPT067
     A 8HVELOCITY,3X,7HSHP PER,2X,10HPROPULSIVE)                        OUTPT068
      WRITE(IPRNT,13)                                                   OUTPT069
   13 FORMAT(4X,3HCFS,5X,8HVELOCITY,3X,5HRATIO,3X,8HVELOCITY,3X,5HRATIO,OUTPT070
     A 4X,7HTURBINE,2X,11HCOEFFICIENT)                                  OUTPT071
      WRITE(IPRNT,10) (Q(I),VJ(I),VJRAT(I),VI(I),VIRAT(I),SHP(I,NSTG),  OUTPT072
     A PC(I),(CONDS(J,I),J=1,2),I=ISTRT,NUMB)                           OUTPT073
   10 FORMAT(F9.2,1X,F9.2,1X,F7.2,3X,F8.2,2X,F6.2,4X,F8.0,2X,F8.4,3X,   OUTPT074
     A 2A4)                                                             OUTPT075
      WRITE(IPRNT,16)                                                   OUTPT076
   16 FORMAT(//,5X,6HRADIUS,5X,4HDUCT,5X,5HANGLE)                       OUTPT077
      WRITE(IPRNT,17)                                                   OUTPT078
   17 FORMAT(5X,5HRATIO,5X,6HRADIUS,3X,7HDEGREES,5X,8HLOCATION,4X,5HSHAPOUTPT079
     AE,/)                                                              OUTPT080
      WRITE(IPRNT,18) (XK(I),RO(I),THATA(I),(ELBWS(L,I),L=1,2),(TYPE(L,IOUTPT081
     A ),L=1,3),I=1,IK)                                                 OUTPT082
   18 FORMAT(6X,F4.2,6X,F4.2,5X,F5.2,5X,2A4,4X,3A4)                     OUTPT083
      WRITE(IPRNT,20)                                                   OUTPT084
   20 FORMAT(//)                                                        OUTPT085
      DO 2 K=1,3                                                        OUTPT086
    2 LABEL(K,12)=ENGN(K,IENGN)                                         OUTPT087
      WRITE(IPRNT,27)                                                   OUTPT088
   27 FORMAT(49X,6HCRUISE,3X,3HT/O,6X,10HEVALUATION)                    OUTPT089
      WRITE(IPRNT,28)                                                   OUTPT090
   28 FORMAT(28X,9HSTRUCTURE,3X,5HWATER,5X,4HDUCT,4X,4HDUCT,8X,4HDUCT)  OUTPT091
      WRITE(IPRNT,29)                                                   OUTPT092
   29 FORMAT(29X,7HWEIGHTS,3X,7HWEIGHTS,3X,6HLOSSES,2X,6HLOSSES,6X,     OUTPT093
     A 6HLOSSES)                                                        OUTPT094
      WRITE(IPRNT,44)                                                   OUTPT095
   44 FORMAT(29X,8H(POUNDS),1X,8H(POUNDS),3X,6H(FEET),2X,6H(FEET),6X,   OUTPT096
     A 6H(FEET),/)                                                      OUTPT097
      DO 5 K=1,14                                                       OUTPT098
      LL=K                                                              OUTPT099
      IF(K.GT.7) GO TO 9                                                OUTPT100
    4 KLL=ISTRT+NUMB-2                                                  OUTPT101
```

```
      GO TO (31,32,33,34,35,36),KLL                                     OUTPT102
   31 WRITE(IPRNT,25) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT103
     A J=ISTRT,NUMB)                                                    OUTPT104
   25 FORMAT(1X,5A4,5X,2F10.1,2F8.2)                                    OUTPT105
      GO TO 5                                                           OUTPT106
   32 WRITE(IPRNT,37) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT107
     A J=ISTRT,NUMB)                                                    OUTPT108
   37 FORMAT(1X,5A4,5X,2F10.1,2F8.2,8X,F8.2)                            OUTPT109
      GO TO 5                                                           OUTPT110
   33 WRITE(IPRNT,38) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT111
     A J=ISTRT,NUMB)                                                    OUTPT112
   38 FORMAT(1X,5A4,5X,2F10.1,2F8.2,4X,2F8.2)                           OUTPT113
      GO TO 5                                                           OUTPT114
   34 IF(ISTRT.EQ.1) GO TO 40                                           OUTPT115
      WRITE(IPRNT,39) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT116
     A J=ISTRT,NUMB)                                                    OUTPT117
   39 FORMAT(1X,5A4,5X,2F10.1,24X,F8.2)                                 OUTPT118
      GO TO 5                                                           OUTPT119
   40 WRITE(IPRNT,41) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT120
     A J=ISTRT,NUMB)                                                    OUTPT121
   41 FORMAT(1X,5A4,5X,2F10.1,5F8.2)                                    OUTPT122
      GO TO 5                                                           OUTPT123
   35 WRITE(IPRNT,42) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT124
     A J=ISTRT,NUMB)                                                    OUTPT125
   42 FORMAT(1X,5A4,5X,2F10.1,20X,2F8.2)                                OUTPT126
      GO TO 5                                                           OUTPT127
   36 WRITE(IPRNT,43) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT128
     A J=ISTRT,NUMB)                                                    OUTPT129
   43 FORMAT(1X,5A4,5X,2F10.1,16X,3F8.2)                                OUTPT130
      GO TO 5                                                           OUTPT131
    9 IF(K.EQ.9) LL=8                                                   OUTPT132
      IF(K.EQ.14) LL=9                                                  OUTPT133
      IF(K.EQ.14) WRITE(IPRNT,26)                                       OUTPT134
   26 FORMAT(  26X,60(1H-))                                             OUTPT135
      IF(LL.NE.K) GO TO 4                                               OUTPT136
      WRITE(IPRNT,25) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2)              OUTPT137
```

```
    5 CONTINUE                                                           OUTPT138
      IF(ISTRT.NE.3)GO TO 100
      DO 101 I=ISTRT,NUMB
      VK(I)=VO(I)*0.5921
      DO 102 J=1,6
      IF(CAV(I,J).EQ.1.)WRITE(IPRNT,200) VK(I),(LOCAT(K,J),K=1,6)
  200 FORMAT(/,39H ***** WARNING CAVITATION OCCURRING AT ,F5.1,6H KNOTS,
     A/,23H AT FOLLOWING LOCATION:,5X,6A4,//)
  102 CONTINUE
  101 CONTINUE
  100 CONTINUE
      WRITE(IPRNT,6)                                                     OUTPT139
      IF(NSTG.EQ.4) NIMP=XIM
      IF(NSTG.NE.4) NIMP=NSTG-1
      WRITE(IPRNT,21)                                                    OUTPT141
   21 FORMAT(15X,9HPUMP DATA,/)                                          OUTPT142
      IF(NSTG.EQ.4) GO TO 48                                             OUTPT143
      WRITE(IPRNT,45) NIMP                                               OUTPT144
   45 FORMAT(38H AXIAL PUMP WITH INDUCER IMPELLER AND ,I2,17H ADDITIONALOUTPT145
     A STAGE,/)                                                          OUTPT146
      GO TO 49                                                           OUTPT147
   48 WRITE(IPRNT,50) NIMP                                               OUTPT148
   50 FORMAT(23H CENTRIFUGAL PUMP WITH ,I2,34H DOUBLE SUCTION IMPELLERS OUTPT149
     APER PUMP,/)                                                        OUTPT150
   49 WRITE(IPRNT,51)                                                    OUTPT151
   51 FORMAT(5X,4HHEAD,4X,4HNPSH,2X,5HTHOMA,5X,3HRPM,3X,10HEFFICIENCY)  OUTPT152
      WRITE(IPRNT,52) (HPP(I),HSV(I),THOM(I),RPM(I,NSTG),ETAP(I,NSTG),  OUTPT153
     A (CONDS(J,I),J=1,2),I=ISTRT,NUMB)                                  OUTPT154
   52 FORMAT(4X,F6.1,2X,F5.1,2X,F5.3,3X,F6.1,4X,F5.3,5X,2A4)            OUTPT155
      IF(ISTRT.EQ.3)GO TO 201
      WRITE(IPRNT,53) XNS(NSTG),SM(2,NSTG),PHI(2,NSTG),SHI(2,NSTG),D1S(N
     ASTG),D2S(NSTG),XLP
   53 FORMAT(/,19H SPECIFIC SPEED,CFS,16(1H.),F7.1,/,                   OUTPT158
     A 27H SUCTION SPECIFIC SPEED,CFS,8(1H.),F7.1,/,                     OUTPT159
     B 17H FLOW COEFFICIENT,13(1H.),F7.3,/,17H HEAD COEFFICIENT,18(1H.),OUTPT160
     C F7.3,/,24H INLET TIP DIAMETER,FEET,11(1H.),F7.2,/,               OUTPT161
```

```
     D 23H EXIT TIP DIAMETER,FEET,12(1H.),F7.2,/,                         OUTPT162
     E 17H PUMP LENGTH,FEET,18(1H.),F7.2)                                 OUTPT163
      WRITE(IPRNT,57) GERAT(NSTG)                                         OUTPT164
   57 FORMAT(11H GEAR RATIO,24(1H.),F7.2,///)                             OUTPT165
      GO TO 208
  201 WRITE(IPRNT,202)
  202 FORMAT(/,15X,15HPUMP PARAMETERS,/)
      WRITE(IPRNT,203)XNS(NSTG),D1S(NSTG),D2S(NSTG),XLP
  203 FORMAT(/,19H SPECIFIC SPEED,CFS,16(1H.),F7.1,/,24H INLET TIP DIAME
     AATER,FEET,11(1H.),F7.2,/,23H EXIT TIP DIAMETER,FEET,12(1H.),F7.2,/,
     B17H PUMP LENGTH,FEET,18(1H.),F7.2)
      WRITE(IPRNT,204)
  204 FORMAT(//,50H PUMP OPERATING PARAMETERS AT EVALUATED CONDITIONS,/)
      WRITE(IPRNT,205)(SM(I,NSTG),I=ISTRT,NUMB)
  205 FORMAT(/,27H SUCTION SPECIFIC SPEED,CFS,8(1H.),3F10.1)
      WRITE(IPRNT,206)(PHI(I,NSTG),I=ISTRT,NUMB)
  206 FORMAT(/,17H FLOW COEFFICIENT,18(1H.),3F10.3)
      WRITE(IPRNT,207)(SHI(I,NSTG),I=ISTRT,NUMB)
  207 FORMAT(/,17H HEAD COEFFICIENT,18(1H.),3F10.3)
  208 WRITE(IPRNT,24)
   24 FORMAT(15X,12HNACELLE DATA,/)                                       OUTPT167
      WRITE(IPRNT,54) DRAT,DM,AI,AIAUX,ELEXT,ELENT                        OUTPT168
   54 FORMAT(21H DIAMETER RATIO,DI/DM,19(1H.),F6.3,/,                     OUTPT169
     A 25H MAXIMUM DIAMETER,DM,FEET,15(1H.),F6.2,/,                       OUTPT170
     B 29H INLET AREA PER NACELLE,FT**2,11(1H.),F6.2,/,                   OUTPT171
     C 39H AUXILIARY INLET AREA PER NACELLE,FT**2,F7.2,/,                 OUTPT172
     D 21H FOREBODY LENGTH,FEET,19(1H.),F6.2,/,                           OUTPT173
     E 16H LIP LENGTH,FEET,24(1H.),F6.2)                                  OUTPT174
      WRITE(IPRNT,55) ELDIF,ELN                                           OUTPT175
   55 FORMAT(21H DIFFUSER LENGTH,FEET,19(1H.),F6.2,/,                     OUTPT176
     A 20H NACELLE LENGTH,FEET,20(1H.),F6.2,//)                           OUTPT177
      TFM=TC*CFM                                                          OUTPT178
      WRITE(IPRNT,47) TC,T,C,T1,C1,TFM,CFM                                OUTPT179
   47 FORMAT(10X,19HSTRUT CONFIGURATION,//,                               OUTPT180
     A 3X,3HT/C,5X,9HTHICKNESS,5X,5HCHORD,/,                              OUTPT181
     B 1X,F5.3,7X,F4.1,8X,F4.1,5X,4HROOT,/,                               OUTPT182
```

```
    C 13X,F4.1,8X,F4.1,5X,3HTIP,/,                                       OUTPT183
    D 13X,F4.1,8X,F4.1,5X,9HWATERLINE,/)                                 OUTPT184
      WRITE(IPRNT,56) (TDRAG(I),POD(I),STRTD(I),SPRAY(I),                OUTPT185
    A (CONDS(J,I),J=1,2),I=ISTRT,NUMB)                                   OUTPT186
   56 FORMAT(10X,14HDRAG ESTIMATES,/,4X,5HTOTAL,5X,7HNACELLE,5X,5HSTRUT,OUTPT187
    A 5X,5HSPRAY,/,(1X,F8.1,5X,F7.1,4X,F7.1,3X,F7.1,5X,2A4))             OUTPT188
      WTRAT=(WGTS(1,14)+WGTS(2,14))/DISP                                 OUTPT189
      WRITE(IPRNT,23) WTRAT                                              OUTPT190
   23 FORMAT(/,30H TOTAL SYSTEM WEIGHT RATIO IS ,F6.4)                   OUTPT191
      IF(ISTRT.NE.3)GO TO 300
      DO 302 I=ISTRT,NUMB
      WRITE(IPRNT,301) VK(I),FRATE(I)
  301 FORMAT(/,25H FUEL CONSUMPTION RATE AT,F5.1,10H KNOTS IS ,F9.1,17H
    APOUNDS PER HOUR,/)
  302 CONTINUE
      RETURN
  300 CONTINUE
      WRATF=(WGTS(1,14)+WGTS(2,14)-WGTS(2,11))/DISP                      OUTPT192
      WRITE(IPRNT,46) WRATF                                              OUTPT193
   46 FORMAT(/,37H SYSTEM WEIGHT RATIO WITHOUT FUEL IS ,F6.4)            OUTPT194
      WRITE(IPRNT,6)                                                     OUTPT195
    6 FORMAT(1H1)                                                        OUTPT196
      RETURN                                                             OUTPT197
      END                                                                OUTPT198
```

```
      BLOCK DATA                                                        BLKDT000
      COMMON /PINLP/ALPHA
      COMMON /WARN/CAV(5,6)
      COMMON /PARMS/ VJVO,VIVO,DIDM                                     BLKDT001
      COMMON /STRTC/TC,T,C,T1,C1,CFM                                    BLKDT002
      COMMON /PUMM/QQ(5),D1S(5),D2S(5),XNS(5),SM(5,5),PLP(5),NSTG,SHI(5,
     A5),XIM
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   BLKDT005
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP               BLKDT006
      COMMON /CONST/PI,G,RHOD                                           BLKDT007
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           BLKDT008
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           BLKDT009
      COMMON /TOLER/DELTA                                               BLKDT010
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   BLKDT011
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PEPF(5,12),ETAP(8,5)      BLKDT012
      COMMON /NACLL/DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN        BLKDT013
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICCMP,NPUMP,NGT,
     AIGEAR
      COMMON /ITABL/L(2)                                                BLKDT015
      DATA IGEAR/99/
      DATA TEMP/59./                                                    BLKDT016
      DATA HS,HE,HCL,XLS,XLPE,XLP/5.,10.,2.,20.,2.,0./                  BLKDT017
      DATA PI,G,RHOD/3.14159,32.174,14.92/                              BLKDT018
C     ENGINE PERFORMANCE DATA                                           BLKDT019
      DATA PERF/2220.,2840.,.59,14500.,1050.,2850.,3060.,.55,14500.,    BLKDT020
     11050.,2800.,3510.,.63,1500.,3200.,2800.,3510.,.63,1000.,3300.,    BLKDT021
     23320.,4250.,.49,3110.,2800.,4160.,5300.,.47,3110.,2800.,          BLKDT022
     32220.,2840.,.79,9000.,1010.,12500.,14000.,.575,5500.,7500.,       BLKDT023
     422200.,22500.,.41,3400.,10500.,19150.,24200.,.52,3600.,14200.,    BLKDT024
     52175).,26950.,.52,3600.,14200.,27600.,34400.,.48,3600.,14200./    BLKDT025
      DATA WGTS,CGS,DELH/155*0./                                        BLKDT026
      DATA DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN/9*1./           BLKDT027
      DATA RO/4*1./,XIM/1./                                             BLKDT028
      DATA TC,T,C,T1,C1,CFM/6*1./                                       BLKDT029
      DATA THATA,XK/3*90.,30.,3*1.5,2./                                 BLKDT030
      DATA SHP/25*1000./,DELTA/.05/                                     BLKDT031
```

```
      DATA VJVO,VIVO,DIDM/1.8,.7,.7/                                    BLKDT032
      DATA Q,VJ,VI,AREA/15*0.,11*1./                                    BLKDT033
      DATA IEQPT,IENGN,IEVAL/0,8,0/                                     BLKDT034
      DATA L/11,1/                                                      BLKDT035
      DATA TYPE/12*4H    /                                              BLKDT036
      DATA NSTG/1/                                                      BLKDT037
      DATA CAV/30*0./
      DATA ALPHA/0./
      END                                                               BLKDT038
```

APPENDIX C

USERS' MANUAL

REQUIRED INPUTS FOR OPTIMIZATION 163

OPTIONAL INPUTS FOR OPTIMIZATION 164

SAMPLE INPUT FOR OPTIMIZATION 165

SAMPLE OPTIMIZATION OUTPUT 167

REQUIRED INPUTS FOR EVALUATION 170

OPTIONAL INPUTS FOR EVALUATION 172

SAMPLE INPUT FOR EVALUATION 173

SAMPLE EVALUATION OUTPUT 176

REQUIRED INPUTS FOR OPTIMIZATION

Symbol	Required Units
VO(1)	feet per second
VO(2)	feet per second
REST(1)	pounds
REST(2)	pounds
STRTD(1)	pounds
STRTD(2)	pounds
SPRAY(1)	Pounds
SPRAY(2)	pounds
POD(1)	pounds
POD(2)	pounds
TRIM(1)	degrees
TRIM(2)	degrees
RANGE	nautical miles
DISP	pounds
BEAM	feet
TYGER	(none)

OPTIONAL INPUTS FOR OPTIMIZATION

Symbol	Required Units	Default Value
XK(1)	(none)	1.5
XK(2)	(none)	1.5
XK(3)	(none)	1.5
XK(4)	(none)	2.0
THATA(1)	degrees	90.
THATA(2)	degrees	90.
THATA(3)	degrees	90.
THATA(4)	degrees	30.
TEMP	degrees Farenheit	59.
HS	feet	5.
HE	feet	10.
HCL	feet	2.
XLS	feet	20.
XLPE	feet	2.
IEQPT	(none)	0
IENGN	(none)	8
IEVAL	(none)	0
NGT	(none)	calculated
NPUMP	(none)	calculated
IGEAR	(none)	calculated
ALPHA	degrees	0.

```
      LOGICAL IFUEL,IPUMP,TYGER
      REAL JANGL
      COMMON /PINLP/ALPHA
      COMMON /PARMS/VJVO,VIVO,DIDM
      COMMON /WARN/CAV(5,6)
      COMMON /NOZL/JANGL
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),
     1 TRIM(5)
      COMMON /NACLL/DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN,AAX(5)
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
      COMMON /CONST/PI,G,RHOD
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /ITABL/L(2)
      COMMON IFUEL,IPUMP,TYGER
C
C     SAMPLE INPUT FOR DESIGN OPTIMIZATION
C
      VO(1)=45.*1.6889
      VO(2)=30.*1.6889
      BEAM=36.
      RANGE=2000.
      HE=35.5
      HS=12.
      XLPE=12.
      IENGN=9
      XLS=32.
      HCL=17.5
      TRIM(1)=0.
      TRIM(2)=0.
      TYGER=.FALSE.
      DISP=750.*2240.
```

```
POD(1)=11436.1
STRTD(1)=11653.7
SPRAY(1)=8474.2
POD(2)=POD(1)*(VO(2)/VO(1))**2
STRTD(2)=STRTD(1)*(VO(2)/VO(1))**2
SPRAY(2)=SPRAY(1)*(VO(2)/VO(1))**2
REST(1)=76956.
REST(2)=129971.6
CALL H2OJT
STOP
END
```

```
CRAFT CHARACTERISTICS

OPERATIONAL

                                  CRUISE               TAKE-OFF

VELOCITY, KNOTS                    45.0                  30.0
TOTAL DRAG, LBS                  108520.               144000.
ANGLE OF ATTACK, DEGREES            0.0                   0.0


CONFIGURATION

AVERAGE BEAM, FEET.........    36.0
DISPLACEMENT, LONG TONS....    750.
ENDURANCE, NM..............   2000.
GAS TURBINE PLANT..........    LM2500


DEPTH OF SUBMERGENCE OF NACELLE................. 12.0  FEET
HEIGHT OF PUMP CENTERLINE ABOVE MEAN WATER..... 35.5  FEET
HEIGHT OF PUMP CENTERLINE ABOVE KEEL........... 17.5  FEET
DISTANCE OF STRUT FROM TRANSOM................. 32.0  FEET
DISTANCE OF PUMP EXIT FROM TRANSOM............. 12.0  FEET


          WATER PROPERTIES
          (ASSUMES STANDARD(3.5% SALINITY) SALT WATER)

TEMPERATURE, DEGREES FAHRENHEIT       59.
DENSITY, LBF-SEC**2/FEET**4           1.989
VISCOSITY, *10**5, FEET**2/SEC        1.279
VAPOR PRESSURE, FEET                  0.545

ACCELERATION OF GRAVITY, FT/SECS**2       32.174
```

```
SPECIFIED NUMBER OF GAS TURBINES IS  2
SPECIFIED NUMBER OF PUMPS IS  2


         *** SYSTEM WEIGHT IS      401.64 TONS ***


NUMBER OF GAS TURBINES IS  2
NUMBER OF PUMPS IS  2


     **** WATERJET PROPULSION SYSTEM OUTPUT DATA ****



INLET AREA, TOTAL, FEET**2   13.41
STRUT DIFFUSER AREA RATIO     1.15
JET AREA, TOTAL, FEET**2      4.89



                        JET               INLET
FLOW RATE    JET     VELOCITY   INLET   VELOCITY   SHP PER  PROPULSIVE
   CFS     VELOCITY   RATIO   VELOCITY   RATIO     TURBINE  COEFFICIENT
  738.75    151.05    1.99     55.10     0.72      15130.    0.5007    CRUISE
  804.32    164.46    3.25     59.99     1.18      22393.    0.2985    T/O


    RADIUS     DUCT     ANGLE
    RATIO     RADIUS   DEGREES     LOCATION    SHAPE

     1.50      2.93     90.00      STRUT       RECTANGLE
     1.50      1.57     90.00      HULL        RECTANGLE
     1.50      2.50     90.00      PUMP        CIRCLE



                                                    CRUISE   T/O      EVALUATION
                              STRUCTURE   WATER      DUCT    DUCT        DUCT
                               WEIGHTS   WEIGHTS    LOSSES  LOSSES      LOSSES
                              (POUNDS)  (POUNDS)    (FEET)  (FEET)      (FEET)

NACELLE                        6535.4       0.0      5.04    6.13
STRUT ELBOW                    3764.2       0.0      1.32    1.53
STRUT DIFFUSER                48006.0   89649.9      0.78    0.92
HULL ELBOW                     2669.6    9319.0      1.10    1.28
ATHWARTSHIPS LENGTH            4619.1   21578.8      0.08    0.09
PUMP ELBOW                     4553.2   14868.8      0.42    0.49
FORE AND AFT LENGTH            3694.4   17258.6      0.06    0.07
PUMP                          31386.6   12345.7
NOZZLE                         4497.1   14888.5      4.09    4.92
REDUCTION GEAR                 5329.3       0.0
FUEL                              0.0  598197.3
LM2500                        21000.0       0.0
JET LIFT                          0.0  -14479.0
                           ------------------------------------------------------------
TOTALS                       136054.7  763627.4     12.90   15.44
```

```
                PUMP DATA

AXIAL PUMP WITH INDUCER IMPELLER AND  0 ADDITIONAL STAGE

   HEAD     NPSH  THOMA     RPM    EFFICIENCY
   313.2    78.0  0.249    620.2     0.908       CRUISE
   431.4    26.4  0.061    705.6     0.920       T/O

SPECIFIC SPEED,CFS.................  149.5
SUCTION SPECIFIC SPEED,CFS........ 1214.6
FLOW COEFFICIENT...................  0.110
HEAD COEFFICIENT...................  0.370
INLET TIP DIAMETER,FEET...........    5.24
EXIT TIP DIAMETER,FEET............    5.24
PUMP LENGTH,FEET..................    9.39
GEAR RATIO........................    4.82


                NACELLE DATA

DIAMETER RATIO,DI/DM.................... 0.562
MAXIMUM DIAMETER,DM,FEET................  5.19
INLET AREA PER NACELLE,FT**2............  6.70
AUXILIARY INLET AREA PER NACELLE,FT**2    0.0
FOREBODY LENGTH,FEET....................  5.61
LIP LENGTH,FEET.........................  0.62
DIFFUSER LENGTH,FEET....................  9.51
NACELLE LENGTH,FEET..................... 28.57


          STRUT CONFIGURATION

  T/C      THICKNESS      CHORD
 0.120        2.2         18.1      ROOT
              2.0         16.9      TIP
              2.1         17.2      WATERLINE

          DRAG ESTIMATES
   TOTAL       NACELLE     STRUT      SPRAY
 109639.3     10755.8    10934.8    8474.1       CRUISE
 145119.2      5082.7     5179.4    3766.3       T/O

 TOTAL SYSTEM WEIGHT RATIO IS 0.5355

 SYSTEM WEIGHT RATIO WITHOUT FUEL IS 0.1795
```

REQUIRED INPUTS FOR EVALUATION

Symbol	Required Units
STRTD(I)	pounds
POD(I)	pounds
SPRAY(I)	pounds
REST(I)	pounds
VO(I)	feet per second
TRIM(I)	degrees
AIN	feet squared
AJET	feet squared
AREA(1)	feet squared
AREA(3)	feet squared
AREA(8)	feet squared
RANGE	nautical miles
DISP	pounds
BEAM	feet
TYGER	(none)
DRAT	(none)
DM	feet
AIAUX	feet squared
ELEXT	feet
ELENT	feet
AI	feet squared
ELAUX	feet
ELDIF	feet
ELN	feet

Symbol	Required Units
TC	(none)
T	feet
C	feet
T1	feet
C1	feet
IEVAL	(none)
IEQPT	(none)
NPUMP	(none)
NGT	(none)
NSTG	(none)
RPM(2,NSTG)	revolutions per minute
QQ(2)	cubic feet per second
D1S(NSTG)	feet
D2S(NSTG)	feet
PLP(NSTG)	feet
HPP(2)	feet
JANGL	radians

OPTIONAL INPUTS FOR EVALUATION

Symbol	Required Units	Default Value
XK(1)	(none)	1.5
XK(2)	(none)	1.5
XK(3)	(none)	1.5
XK(4)	(none)	2.0
THATA(1)	degrees	90.
THATA(2)	degrees	90.
THATA(3)	degrees	90.
THATA(4)	degrees	30.
TEMP	degrees Farenheit	59.
HS	feet	5.
HE	feet	10.
HCL	feet	2.
XLS	feet	20.
XLPE	feet	2.
IENGN	(none)	8
IGEAR	(none)	calculated
ALPHA	degrees	0.
WGTS(2,11)	pounds	0.

```
      LOGICAL IFUEL,IPUMP,TYGER
      REAL JANGL
      COMMON /PINLP/ALPHA
      COMMON /PARMS/VJVO,VIVO,DIDM
      COMMON /WARN/CAV(5,6)
      COMMON /NOZL/JANGL
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),
     1 TRIM(5)
      COMMON /NACLL/DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN,AAX(5)
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
      COMMON /CONST/PI,G,RHOD
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT,
     AIGEAR
      COMMON /ITABL/L(2)
      COMMON IFUEL,IPUMP,TYGER
      DIMENSION SDRG(5),TDISP(5)
C
C     SAMPLE INPUT FOR EVALUATION
C
      VO(1)=45.*1.6889
      VO(3)=40.*1.6889
      VO(4)=45.*1.6889
      VO(5)=50.*1.6889
      BEAM=36.
      RANGE=2000.
      HE=35.5
      HS=12.
      XLPE=12.
      IENGN=9
      XLS=32.
      HCL=17.5
      TRIM(1)=0.
```

```
      TRIM(2)=0.
      TRIM(3)=0.
      TRIM(4)=0.
      TRIM(5)=0.
      TYGER=.TRUE.
      IGEAR=1
      IFVAL=-3
      DISP=750.*2240.
      IFOPT=3
      NGT=2
      NPUMP=2
      SDRG(1)=76956.
      REST(1)=SDRG(1)
      POD(1)=11436.1
      STRTD(1)=11653.7
      SPRAY(1)=8474.2
      SDRG(2)=129971.6
      DO 901 I=3,5
      REST(I)=REST(1)*(VO(I)/VO(1))**2
      STRTD(I)=STRTD(1)*(VO(I)/VO(1))**2
      SPRAY(I)=SPRAY(1)*(VO(I)/VO(1))**2
      POD(I)=POD(1)*(VO(I)/VO(1))**2
  901 CONTINUE
      NSTG=1
      RPM(2,1)=782.9
      QQ(2)=368.89
      HPP(2)=467.7
      D1S(1)=4.92
      D2S(1)=4.92
      PLP(1)=8.81
      AIN=14.79
      AJET=4.31
      AREA(1)=22.4676
      AREA(3)=34.6
      AREA(8)=34.5837
      DRAT=0.731
```

```
      DM=4.20
      AIAUX=0.0
      AI=7.395
      ELAUX=0.0
      ELDIF=3.84
      ELN=23.08
      ELENT=0.19
      ELEXT=1.67
      TC=0.12
      T=2.0
      C=17.0
      T1=1.6
      C1=13.7
      JANGL=.06021
      CALL H2OJT
      STOP
      END
```

```
OPERATIONAL

VELOCITY, KNOTS                 40.0
TOTAL DRAG,LBS,                80272.
ANGLE OF ATTACK, DEGREES         0.0


VELOCITY, KNOTS                 45.0
TOTAL DRAG,LBS,               101276.
ANGLE OF ATTACK, DEGREES         0.0


VELOCITY, KNOTS                 50.0
TOTAL DRAG,LBS,               124689.
ANGLE OF ATTACK, DEGREES         0.0


CRAFT CHARACTERISTICS


CONFIGURATION

AVERAGE BEAM, FEET.........     36.0
DISPLACEMENT, LONG TONS....     750.
ENDURANCE, NM..............    2000.
GAS TURBINE PLANT..........     LM2500


DEPTH OF SUBMERGENCE OF NACELLE................. 12.0  FEET
HEIGHT OF PUMP CENTERLINE ABOVE MEAN WATER..... 35.5  FEET
HEIGHT OF PUMP CENTERLINE ABOVE KEEL........... 17.5  FEET
DISTANCE OF STRUT FROM TRANSOM................. 32.0  FEET
DISTANCE OF PUMP EXIT FROM TRANSOM............. 12.0  FEET


          WATER PROPERTIES
          (ASSUMES STANDARD(3.5% SALINITY) SALT WATER)


TEMPERATURE, DEGREES FAHRENHEIT       59.
DENSITY, LBF-SEC**2/FEET**4           1.989
VISCOSITY, *10**5, FEET**2/SEC        1.279
VAPOR PRESSURE, FEET                  0.545


ACCELERATION OF GRAVITY, FT/SECS**2        32.174
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```
SPECIFIED NUMBER OF GAS TURBINES IS  2
SPECIFIED NUMBER OF PUMPS IS  2


      *** SYSTEM WEIGHT IS     382.79 TONS ***


NUMBER OF GAS TURBINES IS  2
NUMBER OF PUMPS IS  2


    **** WATERJET PROPULSION SYSTEM OUTPUT DATA ****


INLET AREA, TOTAL, FEET**2   14.79
STRUT DIFFUSER AREA RATIO     1.54
JET AREA, TOTAL, FEET**2      4.31


                        JET                INLET
FLOW RATE     JET     VELOCITY    INLET   VELOCITY    SHP PER   PROPULSIVE
   CFS      VELOCITY   RATIO    VELOCITY   RATIO      TURBINE   COEFFICIENT
  587.62     136.48     2.02      39.72     0.59       10905.     0.4521     EVAL 1
  660.37     153.38     2.02      44.64     0.59       14210.     0.4924     EVAL 2
  733.08     170.26     2.02      49.55     0.59       18631.     0.5139     EVAL 3


  RADIUS      DUCT      ANGLE
  RATIO      RADIUS    DEGREES      LOCATION     SHAPE

   1.50       2.37      90.00       STRUT        RECTANGLE
   1.50       1.47      90.00       HULL         RECTANGLE
   1.50       2.35      90.00       PUMP         CIRCLE



                                                 CRUISE    T/O      EVALUATION
                          STRUCTURE    WATER      DUCT     DUCT        DUCT
                           WEIGHTS    WEIGHTS    LOSSES   LOSSES      LOSSES
                          (POUNDS)   (POUNDS)    (FEET)   (FEET)      (FEET)

NACELLE                     2121.9        0.0                      2.08     2.63     3.24
STRUT ELBOW                 1986.1        0.0                      1.97     2.41     2.88
STRUT DIFFUSER             37642.0    93082.9                      2.72     3.37     4.09
HULL ELBOW                  2198.6     7675.1                      0.94     1.15     1.39
ATHWARTSHIPS LENGTH         4160.7    19437.1                      0.07     0.09     0.11
PUMP ELBOW                  3750.0    12245.8                      0.36     0.44     0.53
FORE AND AFT LENGTH         3636.4    16987.9                      0.06     0.08     0.10
PUMP                       27126.9    10206.9
NOZZLE                      4218.8    13087.9                      3.62     4.67     5.83
REDUCTION GEAR              4259.0        0.0
FUEL                           0.0   584766.4
LM2500                     21000.0        0.0
JET LIFT                       0.0   -12143.7
                    -------------------------------------------------------------------
TOTALS                    112100.2   745346.1                     11.83    14.85    18.16

***** WARNING CAVITATION OCCURRING AT  45.0 KNOTS
AT FOLLOWING LOCATION:       STRUT OUTSIDE
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                 PUMP DATA

AXIAL PUMP WITH INDUCER IMPELLER AND  0 ADDITIONAL STAGE

     HEAD     NPSH  THOMA       RPM   EFFICIENCY
     265.9    59.7  0.225     603.4     0.851         EVAL 1
     326.2    76.6  0.235     672.6     0.900         EVAL 2
     393.3    95.5  0.243     742.3     0.919         EVAL 3

                 PUMP PARAMETERS


SPECIFIC SPEED,CFS.................  149.5
INLET TIP DIAMETER,FEET............   4.92
EXIT TIP DIAMETER,FEET.............   4.92
PUMP LENGTH,FEET...................   8.81


PUMP OPERATING PARAMETERS AT EVALUATED CONDITIONS


SUCTION SPECIFIC SPEED,CFS........      481.3      472.0      465.1

FLOW COEFFICIENT..................      0.114      0.115      0.115

HEAD COEFFICIENT..................      0.354      0.349      0.346
                NACELLE DATA

DIAMETER RATIO,DI/DM.................... 0.731
MAXIMUM DIAMETER,DM,FEET................  4.20
INLET AREA PER NACELLE,FT**2............  7.40
AUXILIARY INLET AREA PER NACELLE,FT**2    0.0
FOREBODY LENGTH.FEET....................  1.67
LIP LENGTH,FEET.........................  0.19
DIFFUSER LENGTH.FEET....................  3.84
NACELLE LENGTH,FEET..................... 23.08


          STRUT CONFIGURATION

  T/C       THICKNESS       CHORD
0.120          2.0          17.0      ROOT
               1.6          12.7      TIP
               1.7          14.5      WATERLINE

          DRAG ESTIMATES
   TOTAL       NACELLE       STRUT      SPRAY
 80271.9        6511.5      7423.9     5531.9        EVAL 1
101275.9        8994.9      9223.9     7001.3        EVAL 2
124689.4        9836.2     11202.4     8643.6        EVAL 3

TOTAL SYSTEM WEIGHT RATIO IS 0.5104

FUEL CONSUMPTION RATE AT 40.0 KNOTS IS   10680.9 POUNDS PER HOUR.


FUEL CONSUMPTION RATE AT 45.0 KNOTS IS   13027.0 POUNDS PER HOUR.


FUEL CONSUMPTION RATE AT 50.0 KNOTS IS   15961.7 POUNDS PER HOUR.
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